Biomechanical Evaluation of Le Fort I Maxillary Fracture Plating Techniques

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Purpose: This study used a biomechanical model to examine fundamental questions about rigid plate fixation treatment for maxillary Le Fort I fractures. Specifically, we sought to elucidate the principal strain patterns generated in miniplates and bite force transducers secondary to all masticatory forces, as well as the amount of permanent deformations incurred due to these loading forces.

Materials and Methods: Forty polyurethane synthetic maxillary and mandibular replicas were used to simulate the mandible and maxilla. Ten replicas were controls (group A). The other 30 were divided into 3 groups (10 each), according to the fixation techniques of 3, 2, and 1 miniplates each side (groups B–D), that were osteotomized in the Le Fort I fracture line on the maxilla. Different forces of masseter medial pterygoid, temporalis, and lateral pterygoid muscles were loaded onto the replicas to simulate different functional conditions (anterior incisor, premolar, and molar clenching). Rosette strain gauges were attached at predefined points on the plates and the bite force transducer to compare the stability and bite force of the different fixation methods for maxillary Le Fort I fractures.

Results: Statistically significant differences were found for the deformation of the plates among fixation techniques. The order of stability for each technique was: group B greater than group C greater than group D. In regard to bite force, no difference was found between those found with group A and group B (P > .05), whereas the bite forces of groups C and D were less than those of group A (P < .05).

Conclusions: The fixation of 3 miniplates on each side provides sufficient stability and restores the bite force to the level of the intact maxilla. “The ideal fixation” with 2 miniplates on each side restores 90% of the bite force, and there were more deformations of the miniplates with the “ideal fixation” compared to those found with group B. Group D fixation produced the worst effects for the treatment of maxillary Le Fort I fractures with a weak bite force and insufficient stability.

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The use of rigid plate fixation devices has become common in maxillofacial surgery to treat maxillary fractures and osteotomies. Numerous biomechanical studies illustrate the stability of the rigid fixation for mandibular fractures. However, little research has focused on the maxilla, despite the fact that Le Fort I fractures and osteotomies are common clinical presentations. For the treatment of Le Fort I maxillary fractures, the primary aims include the restoration of correct midfacial vertical height and anterior projection and restoration of occlusion. Nonetheless, the removal rate of the miniplates and screws were approximately 50% in orthognathic surgery (Le Fort I osteotomy), due predominantly to infection or wound dehiscence. The other problem is that patients sometimes complain of weak clenching after the operation. Therefore, questions have arisen regarding the number, size, and ideal placement of plates, as well as the stability and bite force necessary for an optimal outcome for the maxilla. This study was intended to develop a model that answers some of those questions. Most studies have used simple models, in which the models were loaded by a single muscle or bite...
force. However, we developed a physiologically accurate maxilla and mandible model.

To achieve stable fixation and earlier functional movement, this study: 1) describes a physiologic model that can be used to investigate the biomechanics of various craniofacial plates in the maxilla; 2) investigates the strain on the miniplates that were used to treat Le Fort I fractures, and 3) investigates the bite force in different fixation techniques. The purpose of this investigation was to evaluate the biomechanical behavior of different forms of rigid internal fixation (RIF) that are used to reconstruct Le Fort I maxillary fractures.

**Materials and Methods**

**MODEL DEVELOPMENT**

Forty polyurethane synthetic maxilla and mandible replicas (Synbone; AO, Malans, Switzerland) were used in this study. The polyurethane replicas were created to match exactly human anatomy in all dimensions and proportions. The structure of the replicas was similar to human anatomy. These synthetic replicas provide a more uniform and consistent sampling than cadaver bone. Although only similar to bone in their modulus of elasticity, these replicas are able to identify trends and have been used previously for biomechanical research. This study focused on the stress and strain of the miniplates and the bite force under the different clenching conditions, and was dependent primarily on the modulus of elasticity and the structure of the models. To simulate the TMJ articular disc, silicon rubber with a thickness of 2 mm was used in the articular fossa. To simulate Le Fort I maxillary fractures, the models were osteotomized with a fracture line that extended transversely above the tooth roots through the maxillary sinus and nasal septum and posteriorly across the pyramidal process of the palatine bone. To minimize additional variability, all monocortical screws (Titanium, AO/ASIF, Davos Platz, Switzerland) were 7 mm in length, fabricated of titanium, and self-tapping. Ten unsectioned maxilla replicas were used as controls (group A) to assess the bite force with no fracture. The remaining 30 maxillas were sectioned in the right Le Fort I fracture region. They were divided into 3 groups of 10 each (group B, group C, and group D) and reconstructed according to the manufacturer’s recommendations (AO/ASIF), using “L”, “I,” and “Y” shaped miniplates. The miniplates on the biting side were “LB,” “IB” and “YB,” whereas those on the non-biting side were “L,” “I,” and “Y.” The position and type of miniplates are shown in Figure 1. The techniques are delineated in Table 1.

**MUSCLES LOADING**

The masseter, temporalis, and medial and lateral pterygoid were divided into 7 functional groups for which physiologic data were available. The jaw-closing muscles were represented by the anterior, middle, and posterior temporalis, superficial and deep masseter, and medial and lateral pterygoid. The muscles loaded by the spring, which were conjoined at the muscle attachment sites on the mandible and maxillary bone. Groups of parallel vectors simulated 7 pairs of masticatory muscles (superficial and deep masseter; anterior, middle, and posterior temporalis; medial pterygoid and lateral pterygoid) assumed to be directly attached to bone. The directions of the muscles were based on descriptions published previously of musculoskeletal geometry and physical properties of the muscles (Fig 2). The magnitude of the total muscle force \( M_u \) exerted by each muscle during isometric contraction was determined by the following equation: \[ M_u = X_{M_i} \times K \times EMG_{M_i} \]

In the equation, \( X_{M_i} \) is the cross-sectional area of muscle \( M_i \) in cm\(^2\), \( K \) is a general conversion constant.
for skeletal muscle (expressed in N/cm²), and EMG_Mi is the ratio or scaled value of the muscle contraction relative to its maximum possible activity for any task. The product [X_Mi × K] is referred to as the Weighting Factor given to the muscle Mi, and the value EMG_Mi is referred to as its Scaling Factor. In our study, the bite forces of the anterior incisor, premolar, and molar were measured, and the muscle forces under the INC (incisor clenching) and unilateral clenching were used in this study. For all models, the muscle loading of these 2 conditions were same. The muscle groups' attachment sites and the force of the muscle tension under physiologic conditions are shown in Table 2.

According to the muscle length and tension force, the springs were manufactured specifically with the required force for the particular length. All the springs were made of stainless steel. The springs were selected to simulate the muscle tension and had the advantage of being easy to load and able to simulate various groups of muscles simultaneously. During testing, new springs were used with the muscle loading in every model.

**STRAIN GAUGES AND INSTRUMENTATION**

Stacked rosette strain gauges were used to record the deformation of the miniplates and the bite force transducer. Strain gauges were placed in a standardized manner according to the length-axis of the miniplates. The data were gathered by 8-channel data gathering and analyzing instruments (DH 3932, DH 38401).

Data were acquired at a rate of 1,000 Hz and were stored through the use of computer software. Measurements were acquired for the strain of every miniplate and the strain of the bite force transducer. One microstrain is a deformation of 0.0001% of the original length. Positive values represent tensile strains, whereas the same deformation as negative values indicates compressive strain.

**BITE FORCE TRANSDUCER AND CLENCHING POSITIONS**

The bite force was equal to the pressure on the transducer, which was calculated by the strain of the bite force transducer caused the deformation of the transducer, and the resistance of the strain gauges attached to the transducer was recorded. For the purpose of this study, this transducer was designed to record the bite force. The device responded linearly within the range of maximum bite force. The transducer's gap between the maxillary and mandibular tooth was 5 mm. Before the experiment, the relationship between the bite force (N) and the strain of the transducer (µm) was calibrated using weights.

Using linear regression, the bite force (BF) can be calculated using the following formula: $BF = 1.31 \times \text{Strain}$. As the aim of our study was to evaluate the biomechanical behavior of the different fixation forms for Le Fort I fracture, the bite force was the
critical measurement. Therefore, to get more reliable results, the bite forces were measured in 3 teeth. Measurements were taken for second molar clenching as well as for first premolar and central incisor clenching.

**EXPERIMENTAL GROUPS AND SERIES**

The models with 2 mm silicon rubber, simulating the artificial disc, and springs, simulating muscle loading, were divided into 4 groups (groups A to D) with 10 models in each group. Thirty models were sectioned and fixed with the miniplates, which were preshaped to allow for attachment to the bone surface before fixation. The strain gauges on the miniplates and the bite force transducer were attached to the generation and recording instrument.

The static loads were selected in the range of the maximum stresses experienced by the maxilla during masticatory function. At the beginning of each test, a measurement was taken with zero load to “re-zero” the gauges. The results reported are the average of these 3 readings. Recordings of strain data were taken at the initial application of the compressive force and then re-recorded 2 minutes later to allow viscoelastic effects to subside. Data are reported as means with standard deviations, and statistically significant differences within and among categories were determined using an analysis of variance. A $P$ value of less than .05 was considered significant in all cases.

**Results**

**BITE FORCE OF DIFFERENT FIXATION FORMS**

The mean bite forces of each group for the incisor, premolar, and molar are shown in Figure 3. Comparisons of the data between the intact maxilla (group A, control) and the various fixation groups (group B to D) are shown in Table 3. There were no differences in bite force between groups A and B ($P = .09$). Therefore, the fixation of 3 miniplates on each side for Le Fort I fractures can restore the bite force to the level of the intact maxilla. The bite force in group C, which was fixed by 2 miniplates on each side restored the bite force to approximately 90% of control levels, whereas group D restored the bite force to approximately 80% of control levels.

**MINIPLATES DEFORMATION ANALYSIS**

The miniplates’ strains with the different fixation methods (group B to D) are shown in Figure 4. With anterior incisor clenching (Fig 4A), the strains for the left miniplates are approximately the same as the right side ($P > .05$). The “Y” shaped miniplates that were fixed at medial buttresses were under compression. In group C (“Y” and “L” on each side), the “L” strain changed from negative to positive, which indicate they suffered the tension. In group D (only “L” on each side), the “L” miniplate strain increased notably ($P < .05$). With unilateral premolar clenching (Fig 4B), the miniplates on the biting side received a compressive force, whereas those on the non-biting side received a tensile force. In group C, the tensile force of the “Y” and “L” miniplates (on the non-biting side) significantly increased compared to the force in group B ($P < .01$). In group D, the “L” miniplate (on the nonbiting side) was under the tensile strain of 370 $\mu$e. Therefore, the deformation of those miniplates was 370 $\mu$m. With unilateral molar clenching (Fig 4C), the “L$_n$” miniplate (on the biting side) received compressive force whereas the other miniplates received a tensile force. In group C, the tension in the “L” miniplate increased significantly (group C vs group B, $P < .01$). In group D (only “L” miniplates on each side), the “L” miniplate strain was increased to 629 $\mu$e, representing a deformation of 629 $\mu$m.
Discussion

Le Fort I maxillary fractures are among the injuries encountered most frequently in patients who suffer facial trauma and it is common in orthognathic surgery. Fixation of maxillary Le Fort I fractures (osteotomy) by RIF of the facial skeleton has become an accepted, and even expected, form of treatment. When the teeth of the maxilla and mandible are clenched, anatomic support for the midface is provided through a series of buttresses or struts that distribute masticatory forces from the teeth to skull base.\(^\text{19-21}\) The vertical struts of the midface are clinically the most important in management of Le Fort I maxillary fractures. The 3 principal vertical buttresses of the maxilla are the nasomaxillary (medial) buttress, zygomaticomaxillary (lateral) buttress, and the pterygomaxillary (posterior) buttress.\(^\text{4}\) The internal fixation of Le Fort I fractures should use miniplates and screws and be fixed at anterior and lateral buttresses for the ideal internal fixation, whereas the posterior buttress should be without fixation due to the surgical difficulty of the operative approach.\(^\text{4}\) Surgical treatment of Le Fort I fracture according to the “ideal internal fixation” produces satisfactory results, but patients sometimes complain of weak clenching after the operation. Very few comparisons of the different maxilla fixation modalities or biomechanical analyses of their behavior have been reported currently. In clinical Le Fort I fracture treatment, restoration of the correct midfacial vertical height and anterior projection and restoration of occlusion are critical. Therefore, in our study, groups using 3 miniplates (“Y,” “I,” and “L”) on each side and 1 miniplate on (“L”) each side were compared with a group with the ideal internal fixation of 2 miniplates on each side (“Y” and “L”).

Bite force is one of the standards to evaluate functional restoration. Several studies\(^\text{17,22,23}\) found that bite forces shortly after surgery are lower than bite forces recorded later in the postoperative period or in the nonoperated population. The patient senses instability of discomfort maybe the main reason. Sometimes, when patients suffer the MMF after the operation for several days, the bite force was always lower than normal. The muscles’, such as masseter, reattachment that do not finish may also affect the bite force. However, very few studies have examined bite force for the post surgical population. This study was just to compare the bite force under the different fixation technique, whereas the other impact factors such as subjective sense were not considered. Thus meaningful information about mechanical behavior might be obtained by a biomechanical study using muscle loading. Evidence suggests that different muscle loadings affect the strain patterns of the mandible and, therefore, the biomechanical behavior of the maxillary bone and mandible.\(^\text{24}\) Simulated TMJ disc and 4 pairs of muscles were used to develop the more accurate models. In addition, this study measured the bite forces of the different fixation groups for molar, an-
terior incisor, and premolar clenching. In the present experiments, when the Le Fort I maxillary fractures were fixed by 3 miniplates on each side, the bite force was approximately the same as that found with the intact maxilla. These results suggest that this fixation form restores clenching function. The bite force with the fixation of 2 miniplates on each side restores approximately 90% of the physiologic bite force, and the fixation of 1 miniplate on each side restores approximately 80% of the physiologic bite force. This result indicates the lower bite force in group C and group D. In the design of this experiment, the geometry of the models, the mechanical property of the models, and the muscle loading of all models under the different clenching condition were same, whereas only the internal fixation methods were changed. Why did the bite of the same models under the same muscle loadings get different results? How do the plating techniques affect the bite force? We had investigated that the fracture gap was open or rotational and miniplates were bending when the muscle loadings happened. Therefore, we can imagine that the interface between miniplate and screw and the interface between the screw and bone must have some displacement. The local displacement due to the local stress may affect the bite force, whereas the plating technique will affect the degree of local displacement. The local displacement of the fracture gap was more visible in group D than in group C, and it was not visible in group B. In this study, we could not get

**FIGURE 4.** Graphic demonstration of the mean strain of the miniplates for each group. “LB, IB, YB, Y, I, L” represent the different miniplates shown in Figure 1. When the strain is positive, the stress is tension; when the strain is negative, the stress is compression. A, Anterior incisor clenching. B, Premolar clenching. *(Figure 4 continued on next page.)*

the precise local stress and strain on mandible, maxilla, or condyle. In our farther study, the computer model will be used in 3D finite element analysis to understand the local strain of the bone, the teeth, and the miniplates.

The strains of the miniplates were measured in this study. It was expected that the miniplates’ fixation would result in sufficiently low fracture mobility. When the gap between the bone mass is beyond a certain limit, the mobility will be reduced. The possible causes that account for the permanent gap changes include: 1) bending of the plate; 2) axial deformation of the plate; 3) movement at the bone-screw interface; and 4) movement at the plate-screw interface. Our theoretic analysis rules out axial deformation as the principal cause of the permanent gap change. For strictly axial forces, the miniplates would be under compressive or tensile forces in different fixation forms and different clenching positions. With Le Fort I fractures, the mass of the bone is separated, and the clenching position acts as a fulcrum while the bone mass is tilted under the loaded muscle. The miniplates close to the clenching position came under compressive force, whereas the miniplates far from the clenching position came under tensile force. For example, the miniplates on the nonbiting side expressed tension, and the deformation of the “L” miniplate was noticeable. With anterior incisor clenching, the “Y” and “YB” miniplates were not different. However, in groups C and D, the deformation of “L” increased. For the premolar and molar clenching, the “L” miniplate (on the nonbiting side) came under the greatest tension according to the following order: group D greater than group C greater than group B. When molar clenching, in group D, the deformation of the “L” miniplate (non-biting side) was 628 με with molar clenching, which is beyond the ideal displacement of the gap (100 to 150 μm).25-27 This form of fixation seems to be unstable. In group C, the deformation of the “L” miniplates (on the non-biting side) was 492 μm with molar clenching, but, despite the fracture gap was stable with incisor and premolar clenching. Even though the limited gap displacement of mandible was very small, the permitted gap displacement of the maxilla should be larger than “the ideal displacement” for better blood supply. However, studies have not examined the limit of the displacement in a maxillary fracture. We can only compare the gap displacement of each group, and we cannot conclude whether the fixation of the group C was stable.

The current study developed a functional rigid internal fixation model of maxillary and mandibular fracture to examine anterior incisor, premolar, and molar clenching and compared the stability of several fixation methods for maxillary Le Fort I fractures. The fixation of 2 miniplates on each side is suggested by AO/ASIF. However, in the current study we found that the fixation of 3 miniplates on each side provides sufficient stability and restores the bite force to the level of the intact maxilla, whereas “the ideal fixation” with 2 miniplates on each side restores only 90% of the bite force and leads to deformations of the miniplates that are greater than those found with 3 miniplates. Fixation with only 1 miniplate on each side produces a weak bite force and insufficient stability and, thus, the poorest results for the treatment of maxillary Le Fort I fractures.

References


