Analysis of Stress Distribution on Fixation of Bilateral Sagittal Split Ramus Osteotomy With Resorbable Plates and Screws Using the Finite-Element Method

*Farzin Sarkarat, DMD,**
Mohammad Hosein Kalantar Motamedi, DDS,†
Behnam Bohluli, DMD,‡ Nima Moharamnejad, DMD, BSc,§
Shirin Ansari, DDS,‖ and Hale Shahabi-Sirjani, DDS¶

Purpose: To determine the most appropriate stress distribution in fixation with resorbable screws and plates after bilateral sagittal split ramus osteotomy using the finite-element method.

Materials and Methods: This experimental study was performed on simulated human mandibles using computer software. The osteotomy line was applied to the simulated model and experimental loads of 75, 135, and 600 N were exerted on the model in accordance with the vector of occlusal force. The distribution pattern of stress was assessed and compared in 8 fixation methods: 1 resorbable screw, 2 resorbable screws in a vertical pattern, 2 resorbable screws in a horizontal pattern, 3 resorbable screws in an L pattern, 3 resorbable screws in a backward-L pattern, 1 miniplate with 2 screws, 1 miniplate with 4 screws, and 2 parallel miniplates with 4 screws each.

Results: Among the simulated fixations, 2 parallel miniplates showed the greatest primary stability and the single screw and the 2-hole miniplate showed the least tolerance to posterior forces.

Conclusions: This study showed the 2-miniplate/4-hole plate pattern was the strongest and the single-screw and 2-hole plate patterns were the weakest of fixations in this bilateral sagittal split ramus osteotomy model. The finite-element method showed that polymer-based resorbable screws and plates (polyglycolic acid and D,L-polylactide acid) provide satisfactory primary stability in this model.
© 2012 American Association of Oral and Maxillofacial Surgeons
J Oral Maxillofac Surg 70:1434-1438, 2012

There are 2 methods of fixation for bilateral sagittal split ramus osteotomy (BSSRO): wire osteosynthesis and internal rigid fixation. The latter is better for stability.[1-5] Fixation can be performed using many different types of materials such as titanium and resorbable plates. Titanium is the most common material used for plates and screws and is the gold standard for rigid-fixation plates and screws. It is biocompatible, strong, and stiff. However, finding titanium particles in tissues and in the pulmonary system and the need for removal (eg, in children) are of concern.[6,7] Greater use of resorbable fixation during the previous 2 decades has been reported.[1-5] However, few studies on bioresorbable fixation methods for BSSRO using the finite-element method (FEM) have been performed.

The present study was undertaken to determine whether bioresorbable fixation methods have enough

*Assistant Professor, Department of Oral and Maxillofacial Surgery, Buali Hospital, Azad University of Medical Sciences, Tehran, Iran.

†Professor, Trauma Research Center, Baqiyatallah University of Medical Science and Azad University of Medical Sciences, Tehran, Iran.

‡Assistant Professor, Department of Oral and Maxillofacial Surgery, Buali Hospital, Azad University of Medical Sciences, Tehran, Iran.

§Craniomaxillofacial Research Center, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran.

‖Private Practice in Dentistry, Tehran, Iran.

¶Private Practice in Dentistry, Tehran, Iran.

Address correspondence and reprint requests to Dr Motamedi: Africa Expressway, Golestan St, Giti Blvd, No 16, Tehran 19667, Iran; e-mail: motamedical@lycos.com
© 2012 American Association of Oral and Maxillofacial Surgeons
0278-2391/12/7006-0$36.00/0
doi:10.1016/j.joms.2011.05.017

primary stability to be an alternative for titanium. This study analyzed the biomechanical stress distribution around screws in 8 different methods of fixation with resorbable plates and screws in simulated BSSRO using the FEM.

Materials and Methods

This experimental study was performed on a 3-dimensional simulated model of a mandible using computer software from a computed tomographic scan of a human mandible. The osteotomy line was applied on the simulated model according to BSSRO using a 0.5-mm tolerance space. All models were then assembled using 8 different methods of resorbable fixation.

1. One transverse bicortical screw was placed through the buccal cortex distal to the osteotomy line close to the superior border of the mandible (Fig 1).
2. Two transverse bicortical screws were placed in a vertical manner distal to the osteotomy line. The upper screw was close to the superior border and the lower screw was close to the inferior border of the mandible; the distance between screws was 3 cm (Fig 2).
3. Two transverse bicortical screws were placed in a horizontal manner distal to the osteotomy line close to the superior border of the mandible; the distance between screws was 10 mm (Fig 3).
4. Three transverse bicortical screws were placed in an L pattern placed distal to the osteotomy line. The distance between the anterior and posterior screws was 10 mm. The vertical distance between the superior and inferior screws was 30 mm (Fig 4).
5. Three transverse bicortical screws were placed in in an inverted-L pattern distal to the osteotomy line. The distance between the anterior and posterior screws was 10 mm. The vertical dimension between the superior anterior and inferior screws was 30 mm (Fig 5).
6. One miniplate with 2 monocortical screws was placed in the middle third of the mandible body through the buccal cortex (Fig 6).
7. One miniplate with 4 monocortical screws was placed in the middle third of the mandible body through the buccal cortex (Fig 7).

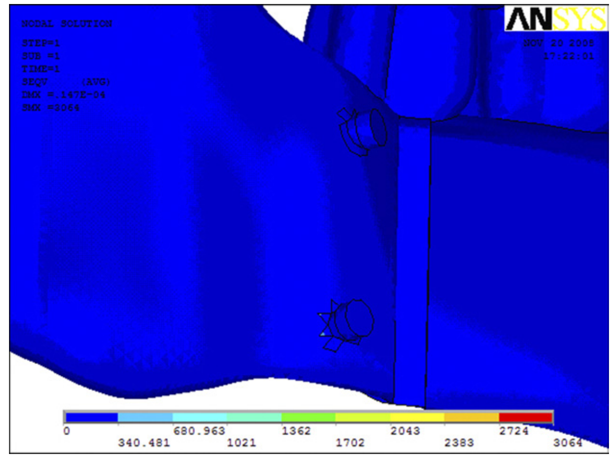

FIGURE 2. Two transverse bicortical screws placed in a vertical manner distal to the osteotomy line.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

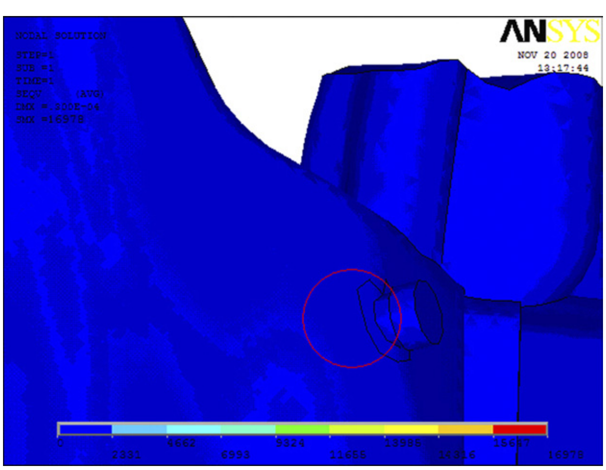

FIGURE 1. One transverse bicortical screw placed in the buccal cortex distal to the osteotomy line close to the superior border of the mandible.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

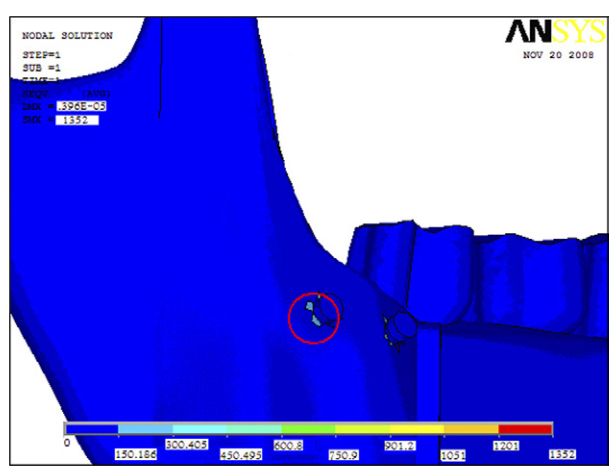

FIGURE 3. Two transverse bicortical screws placed in a horizontal manner distal to the osteotomy line.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

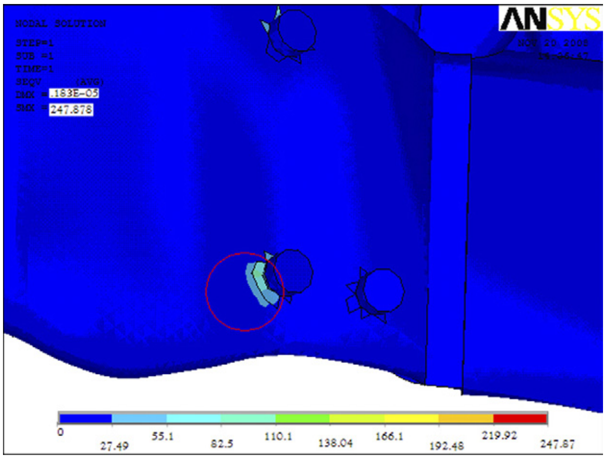

FIGURE 4. Three transverse bicortical screws in an L pattern placed distal to the osteotomy line.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

8. Two parallel miniplates were placed: 1 plate with 4 screws near the superior border and the other plate with 4 screws near the inferior border of the mandible (Fig 8).

The length of the bicortical screws was 11 mm and the diameter was 2 mm. The monocortical screws that were used with plates measured 6 mm in length and 2 mm in diameter. The thickness of the plates was 1.3 mm and measured 5 × 25 mm.

The meshing process divided the primary structure into segments; each point angle of these segments had a node. By increasing the number of these nodes, a more realistic model was simulated.

The vector of force was divided among the posterior teeth. The first premolar, second premolar, first molar, and second molar were placed under force.

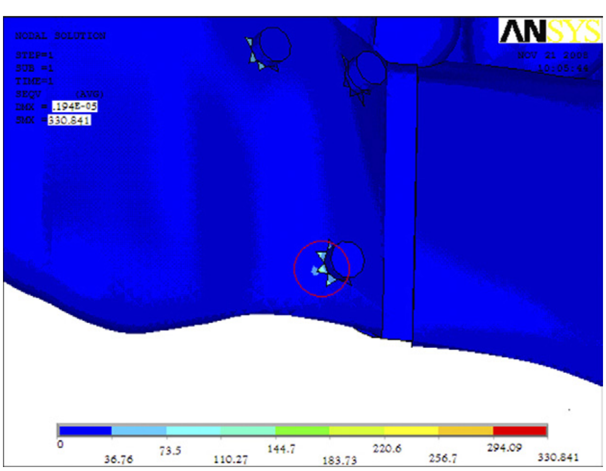

FIGURE 5. Three transverse bicortical screws in an inverted-L pattern placed distal to the osteotomy line.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

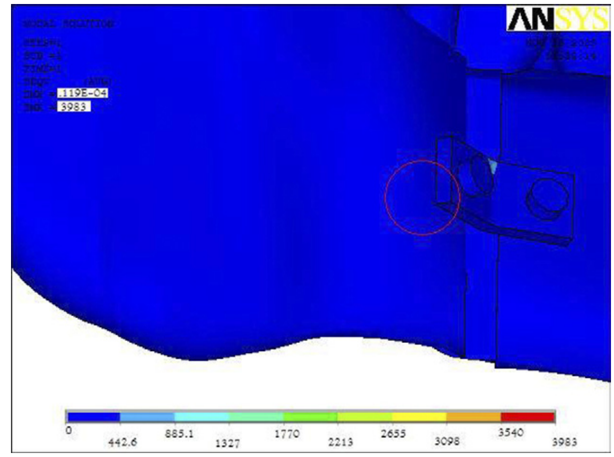

FIGURE 6. One miniplate with 2 monocortical screws placed in the middle third of the mandibular body on the buccal cortex.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

The models were assessed for nonlinear mechanical analysis with the FEM. Homogeneous and isotropic forces on the mandible and teeth were simulated.

The resorbable plates and screws were fabricated from polymers (polyglycolic acid and D,L-polylactide acid). Von Mises stresses on screws (megapascals) were measured.

The Poisson ratios of the model and resorbable plates and screws were almost the same (0.03), and the assigned moduli of elasticity of bone and fixations were 14.8 and 114 MPa, respectively. Cube meshing was applied for each element (0.9-mm dimension). The meshing was applied to input data from the computed tomogram, which included mandibular bone and teeth.

The condylar head was considered a fulcrum and the linear vertical load, perpendicular to the occlusal plane, was applied to the middle third of the simu-

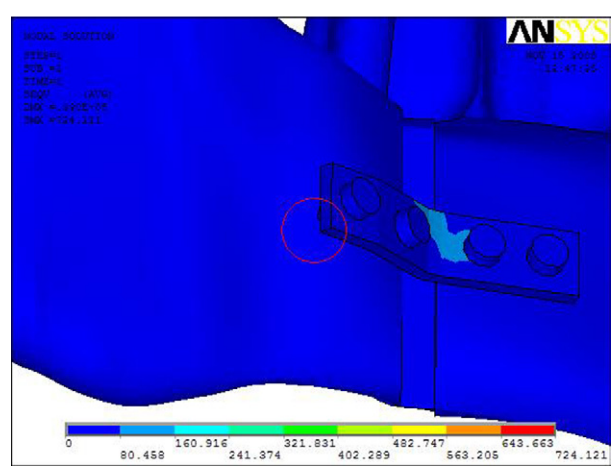

FIGURE 7. One miniplate with 4 monocortical screws placed in the middle third of the mandibular body on the buccal cortex.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

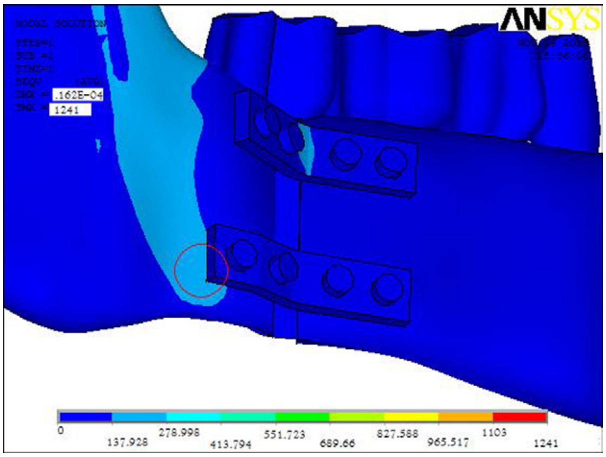

FIGURE 8. Two parallel miniplates: 1 plate with 4 screws placed on the superior border and the other plate with 4 screws placed on the inferior border of the mandible.

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

lated crowns of posterior teeth. The magnitudes of load were set at 75, 135, and 600 N. The stress distribution at fixation points was assessed by computer software. A 3-dimensional model was produced using Catia 7 (Dassault Systemes, Vélizy-Villacoublay, France) and the stress analysis of models was evaluated using ANSYS 10 (ANSYS, Canonsburg, PA).

Results

The 8 simulated models were divided into 3 groups based on the vertical loads. A color scale with 9 stress values presented the stress distribution on the fixation points. Table 1 presents the stress distribution of each group. If the stress exceeded the modulus of elasticity of bone, the structure was distorted. The single plate with 2 screws showed the greatest stress at 600 N, whereas the 2 parallel miniplates with 4 screws per plate showed the lowest (Fig 1).

Discussion

Many engineering studies have investigated internal fixation methods, but few have considered clinical factors (ie, 3-dimensional model and masticatory forces after surgery).[1] Assessment of stress distribution in 3-dimensional models is an advantage of the FEM.[1] The FEM is a computerized numerical analysis technique that can be used to determine the stress distribution of fixations.[1] The FEM is a mathematical model that simplifies a complex structure to a simple linear shape. The calculation of the mechanical behavior of these simplified structures and the interaction of these structures can be analyzed with the FEM. These models are nearly realistic; however, these models always differ from reality because of biotypes such as dissimilarity between genders, race, bone quality, etc. The accuracy of results depends on the details of the network on the models.[1,3,5] The present study used models consisting of 343,600 nodes and 236,800 elements. The stress distribution around the resorbable fixations was assessed using simulated masticatory forces after BSSRO was performed. The masticatory forces used in this study were based on previous research. Gerlach et al[8] in 2002 showed that masticatory forces 1 week and 6 weeks after surgery were 69.91 and 130.43 N, respectively. The fixation methods in the present study showed tolerable stress around the screws. The single screw was the weakest. Two bicortical fixation screws exert forces between the proximal and distal segments; as a result, this phenomenon adds a frictional resistance along the contact surface of segments greater than 2 extra fixation points on a plate with a monocortical 4-screw configuration. The values show that the single screw and 2-hole plate pattern are more susceptible to failure; nevertheless, in vivo fixation failure may be influenced by patient factors (muscular strength, diet, etc) and the surgical procedure (adaptation of segments, etc). The reason for choosing resorbable plates and screws for the present study was to determine whether they could tolerate these forces (because they are less rigid). A clinical study by Rasse et al[9] showed that at 12 months the resorbable fixations degraded, with no foreign body reaction and no resorption of underlying bone. Cilasun et al[10] in 2006 reported no significant differences in stability between bones fixed with titanium and those fixed with resorbable screws. Cox et al[3] studied a computer analysis on resorbable fixation and concluded that resorbable polymer-based plates and screws are of adequate strength and stiffness to fixate mandibular angle fractures. However, they did not compare dif-

TABLE 1. STRESS VALUE ON RESORBABLE FIXATION WITH VERTICAL LOADS OF 75, 135, AND 600 N

Model	Stress on Screw (MPa)		
1 screw	2.249	4.008	16.978
2 screws in vertical pattern	0.386	0. 689	3.064
2 screws in horizontal pattern	0.758	1.352	5.002
3 screws in L pattern	0.247	0.441	1.963
3 screws in backward-L pattern	0. 330	0.589	2.620
1 plate with 2 screws	2. 235	3.983	17.699
1 plate with 4 screws	0.724	1.290	5.734
2 parallel miniplates with 4 screws each	0.156	0.279	1.241

Sarkarat et al. Stress Distribution by Finite Element Method. J Oral Maxillofac Surg 2012.

ferent patterns of fixation. Ferretti and Reyneke[11] showed that resorbable fixation of a BSSRO is a viable alternative to titanium screws for the fixation of advancement BSSRO.

ELASTIC PROPERTIES AND YOUNG MODULUS FOR TITANIUM

To describe the elastic properties of linear objects such as wires, rods, or columns that are stretched or compressed, a convenient parameter is the ratio of stress to strain, a parameter known as the *Young modulus* or *modulus of elasticity* of the material. The Young modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material.

Strain

Strain can be expressed as dL/L, where dL represents elongation or compression (offset) of the object in meters or inches and L represents the length of the object in meters or inches.

Stress

Stress can be expressed as F/A, where F represents force in newtons or pounds and A represents the area of the object in square meters or square inches.

Young Modulus (Tensile Modulus)

The Young modulus, or tensile modulus, can be expressed as E = stress/strain = (F/A)/(dL/L), where E represents the Young modulus (newtons per meter squared or pounds per square inch).

Elasticity

Elasticity is the property of an object or material that will restore it to its original shape after distortion. A spring is an example of an elastic object—when stretched, it exerts a restoring force that tends to bring it back to its original length.

The typical mechanical properties for polylactide include a modulus of elasticity of 3,250 MPa and a stress at break of 57 MPa, whereas the modulus of elasticity of titanium is 110,316 MPa (16×10^6 psi). In other words, polylactide is 34 times more deformable than titanium. Use of bioresorbable plates has been suggested to eliminate potential postoperative hardware complications. All combinations of titanium and resorbable plates may be sufficient to overcome the displacing forces produced by the masseter and may be used for internal fixation of some fractures in the adult.[12,13] Biological materials have dynamic behavior; they may have isotropic properties in 1 direction and heterogeneous properties in another direction. These are the constitutional limitations of the FEM.[12]

This study showed the 2 miniplate/4-hole plate pattern was the strongest and that the single screw and 2-hole plate pattern constituted the weakest methods of fixations in this BSSRO model. Polymer-based resorbable screws and plates (polyglycolic acid and D,L-polylactide acid) provided satisfactory primary stability.

References

1. Erkmen E, Simşek B, Yücel E, et al: Comparison of different fixation methods following sagittal split ramus osteotomies using three-dimensional finite elements analysis. Part 1: Advancement surgery-posterior loading. Int J Oral Maxillofac Surg 34:551, 2005
2. Ozden B, Alkan A, Arici S, et al: In vitro comparison of biomechanical characteristics of sagittal split osteotomy fixation techniques. Int J Oral Maxillofac Surg 35:837, 2006
3. Cox T, Kohn MW, Impelluso T: Computerized analysis of resorbable polymer plates and screws for the rigid fixation of mandibular angle fractures. J Oral Maxillofac Surg 61:481, 2003
4. Kiely KD, Wendfeldt KS, Johnson BE, et al: One-year postoperative stability of Le Fort I osteotomies with biodegradable fixation: A retrospective analysis of skeletal relapse. Am J Orthod Dentofac Orthop 130:310, 2006
5. Uckan S, Veziroglu F, Soydan SS, et al: Comparison of stability of resorbable and titanium fixation systems by finite element analysis after maxillary advancement surgery. J Craniofac Surg 20:775, 2009
6. Frisken KW, Dandie GW, Lugowski S, et al: Study of titanium release into body organs following the insertion of single threaded screw implants into the mandibles of sheep. Aust Dent J 47:214, 2002
7. Haraji A, Motamedi MH, Moharamnejad N: Causes and incidence of miniplate removal following le Fort I osteotomy. Eplasty 9:e45, 2009
8. Gerlach KL, Schwarz A: Bite forces in patients after treatment of mandibular angle fractures with miniplate osteosynthesis according to Champy. Int J Oral Maxillofac Surg 31:345, 2002
9. Rasse M, Moser D, Zahl C, et al: Resorbable poly(D,L)lactide plates and screws for osteosynthesis of condylar neck fractures in sheep. Br J Oral Maxillofac Surg 45:35, 2007
10. Cilasun U, Uckan S, Dolanmaz D, et al: Immediate mechanical stability of sagittal split ramus osteotomy fixed with resorbable compared with titanium bicortical screws in mandibles of sheep. Br J Oral Maxillofac Surg 44:534, 2006
11. Ferretti C, Reyneke JP: Mandibular, sagittal split osteotomies fixed with biodegradable or titanium screws: A prospective, comparative study of postoperative stability. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 93:534, 2002
12. Bohluli B, Motamedi MH, Bohluli P, et al: Biomechanical stress distribution on fixation screws used in bilateral sagittal split ramus osteotomy: Assessment of 9 methods via finite element method. J Oral Maxillofac Surg 68:2765, 2010
13. Hanemann M Jr, Simmons O, Jain S, et al: A comparison of combinations of titanium and resorbable plating systems for repair of isolated zygomatic fractures in the adult: A quantitative biomechanical study. Ann Plast Surg 5:402, 2005