Journal of Craniomaxillofacial Research

Vol. 6, No. 3 Summer 2019

The comparison of three different fixation methods on bilateral sagittal split ramus osteotomy mandibular on a 3D of fully modelled mandible by the finite element method

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ARTICLE INFO

Article Type:
Original Article

Received: 21 Apr. 2019
Revised: 8 Jun. 2019
Accepted: 15 Jul. 2019

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ABSTRACT

In this paper, a full mandibular CT-scan in a specific patient is used to model BSSO surgery. The purpose is to compare the three most common fixation methods which are used in BSSO surgery by finite element method. Three different fixations are studied in order to obtain the minimum displacement of the lower jaw and optimum stress and strain on the specified fixation. The methods are two parallel plates with four screws, the operation of triangular screw configuration and one plate with four screws. The plates and the screw are modeled precisely by point clouds of Synthes Brand's plate and screw. The mechanical properties of the full mandibular and, to obtain a practical model after the surgery, the mean jaw forces are extracted from literatures. It is resulted that the minimum displacement and stresses on the mandible and fixation tools happened in the Triangular screw configuration model and the two other methods have higher stress and lower displacement. Therefore, the mandibular in triangular method, experiences little deformation and the screws toler-ates lower stress and strain which is better than the other two methods.

Keywords: Finite element analysis; Sagittal split ramus osteotomy; Parallel plates; Triangular screw.

Introduction

By developing new methods in the finite element analysis (FEA) and computer aided simula-tions, analysis of the optimal fixation methods are more reachable and can be done before each sur-gery of mandible. Regarding this issue, in this paper, an analysis is performed on a healthy patient's mandible to extract the difference of these methods by using finite element methods software AN-SYS workbench. Bilateral sagittal split ramus osteotomy is the correction of dento-facial abnormalities [1]. This kind of surgery has been operated since the 1800s and it has been modified in the 1960s and 1970s which made it be accepted widespread. These modifications were in the direction to make the sur-gery more reliable, safer and predictable with a lower risk of getting to the initial state [2]. These modifications are still in progress to help the patient for faster healing and the shortest surgery time. These modifications include fixation methods and tools [3]. The final result of these kinds of surgeries is dependent on different parameters such as cortical bone strength, mandible orientation, fixation methods and most of the entire surgeon's experience. Different techniques are used to fix a broken mandible and also for bilateral sagittal split surgery. Their difference includes a number of plate and screws, the material of plate and screws, the angle between the plates fracture line, the screws insertion angle, screws coordinates in surgeries with techniques such as triangular screw fixations [6]. In all these methods, the surgeon purpose is the patient better healing and better results. Using an efficient technique not only reduces the operation time but also reduces the healing period. There are two opposing influences for a surgeon to choose between the techniques. The type of fixation must fulfil the anatomical and clinical restrains by implanting minimum size for the fixation. Therefore, when the plates and fixation are small enough, that would be a beneficiary. On the other hand, the fixation must have sufficient stability to permit fracture healing to occur [7]. The outcome of a surgery would be satisfactory when the used plates and screws could bear the ultimate stress which is a result of patient's bite force.

Materials and Methods

In this paper, the geometry section contains two parts. The first section is the mandibular model on which the bilateral split ramus osteotomy surgery is done, and the second part is the fixation tools which must be modelled precisely to get accurate results.

Mandibular Geometry

A three-dimensional finite element model of a healthy mandible is constructed from a series of CT-Scan files which has serial sections of 0.5mm apart [8]. by Using image-processing software (Mimics 17.0; Materialise, Leuven, Belgium), the scanned profiles in DICOM format were translated into 3-D models and were saved as stereo lithography files (Figure 1). These files were imported into reverse engineering software (Geomagic Studio 12.0; Geomagic, Inc., Research Triangle Park, NC) as the polygon data. The procedure of constructing a well-shaped geometry in Geomagic software basically consists of two different steps. In the first step, Polygon Phase, small surface holes were filled and the "Relax" and "Sandpaper" commands were used to smooth and flatten the model surface. By the second step called Shape Phase, the model contours were detected and optimized (Figure 2). Patches and grids were constructed on the surface. A non-uniform rational basis spline (NURBS) surface in each patch was generated by the "Fit Surface" command. Finally, the NURBS models were converted into CAD (computer-aided design) models. The solid model was generated and saved as the Initial Graphics Exchange Specification (IGES) data. These IGES files are imported into other commercial software (Abaqus™) to operate the bilateral sagittal split ramus osteotomy (BSSO) for a mandible expansion surgery. The geometry of the driven surgery is elaborated in (Figure 3). This operation is done based on the experience of Dr Parhiz surgeries on different patients. The purpose of this surgery is to expand the mandible by 2 millimetre forward. In this paper, due to the fact that the tensile strength of the mandible and the fixation is under investigation, the spongy bone of the mandible is not modelled since its module of elasticity is low and its effect on the analysis is small enough which can be eliminated and the geometry is simplified.

Plate and screw model

In order to model the fixation tools, the point cloud method is used to construct them perfectly. Point cloud method is mainly used to model the exterior surface of complicated geometries which the dimensions are not defined accurately in the literature. By this method, a 3D scanner is used and measured which its output is a cloud of point in an X-Y-Z coordinate system which can be a surgical plate which is shown in (Figure 4) and has 25 millimetres length with 1mm thickness and the holes of 2.235 millimetres diameter. Also, the screw model is shown in (Figure 5) and has 15 millimetres length.

Material properties

In Table 1, the mechanical properties of the mandible and fixation tools are demonstrated. Due to literature [1], both mandible and plates and screws are assumed to have isotropic material properties.

Methods

Finite Element Analysis is considered to be a helpful procedure in discretising complex geometries with grids and solving the governing elastic equations for the obtained matrixes. The first step to get precise results depending on the geometry is to build an independent grid. In this article, a mesh study is done to get the best results which must be independent of the grid density. Total mesh nodes are 545,009 and total elements are 493,064. The mandible has an unstructured grid with an element size of 0.001 and screw and plates have 2.5E-4 element size. The plate was mostly meshed with structured hexagonal elements.

Three Different Fixation Methods

In order to fix the mandible and achieve bone recovery after the surgery, surgeons use different methods of fixation based on their experience and expertise. To magnify these methods differences in this paper, three usual methods used in this kind of surgeries are investigated.

1. One plate

In this method, as shown in (Figure 7), on each side, one plate with four screws is used to hold the mandible. The plate orientation is perpendicular to the fracture line. This kind of fixation is very common.

2. Two-parallel plates

In this type of fixation, on each side, two parallel plates are located perpendicular to the bone fracture. In this type of fixation, the two parts of the mandible are firmly attached to each other and as to be expected, the deformation in this kind of fixation is lower than the one plate method.

3. Triangular Screw fixation

In this method, which is the simplest internal fixation (Figure 9), the bone fragments are attached to each other without using a plate. This kind of fixation is widely applied and the stability of this fixation is studied in the literature [9].

a

b

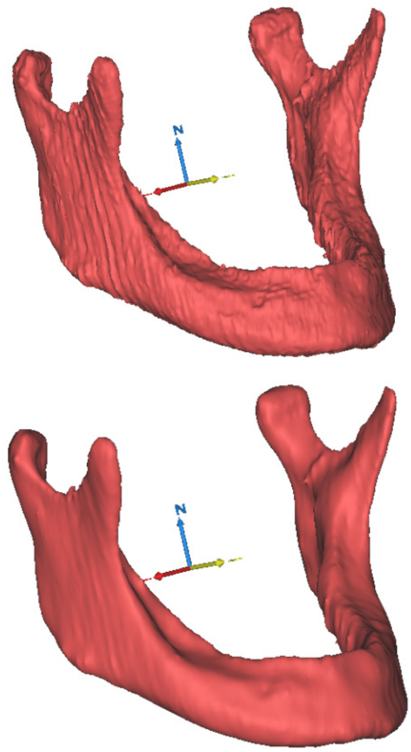

Figure 1. The mimics software stereo lithography files a) primary file b) after smoothing.

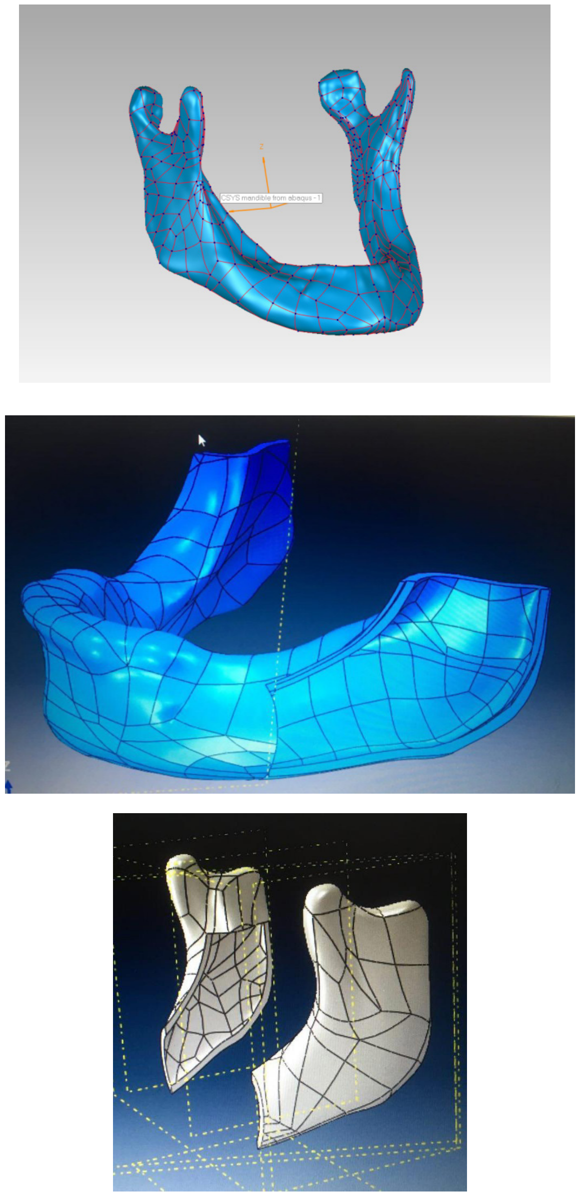

Figure 2. The finalized model of the mandibular.

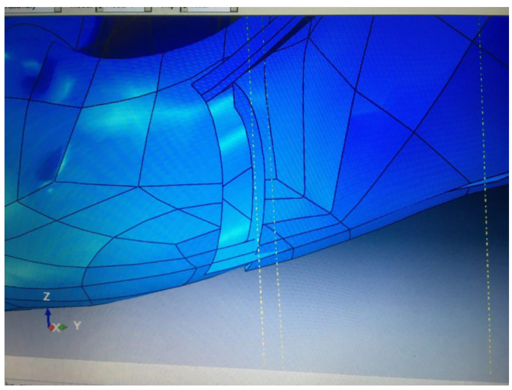

Figure 3. BSSO geometry.

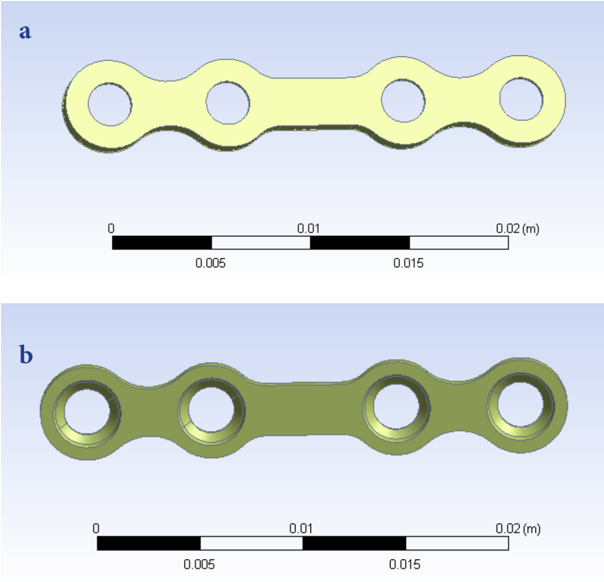

Figure 4. The fixation plate model a) behind view b) front view.

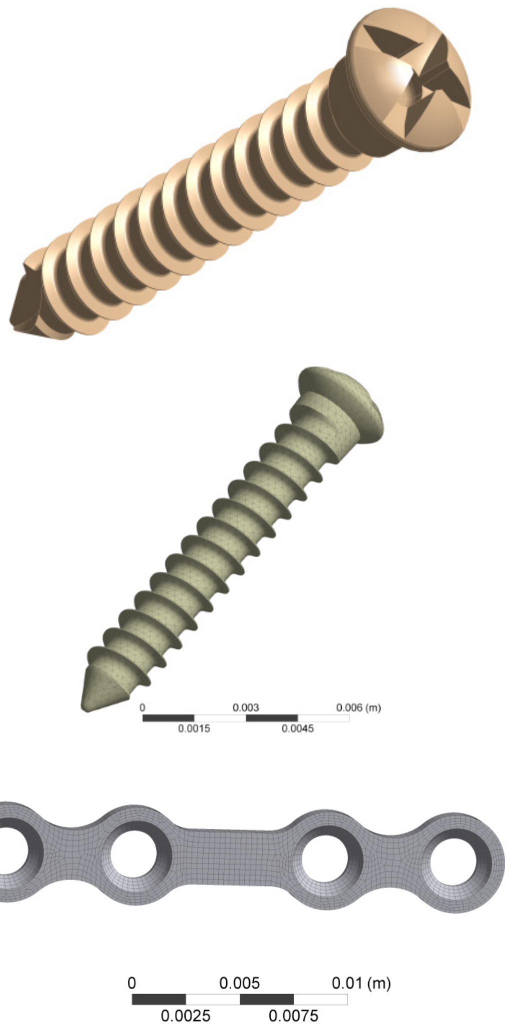

Figure 5. The fixation screw and plate model.

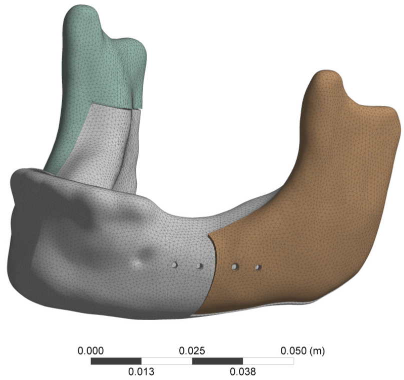

Figure 6. The geometries Grid.

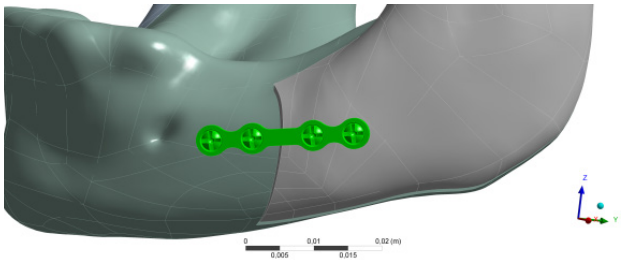

Figure 7. The one-plate fixation.

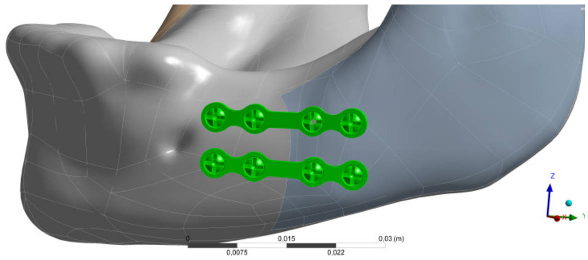

Figure 8. The two parallel plates fixation.

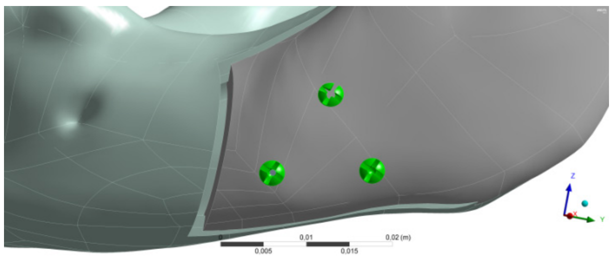

Figure 9. The triangular Screw fixation.

Mandible	
Young's Modulus	14,800 MPa
Poisson's Ratio	0.2817
Plates and Screws (Stainless Steel)	
Young's Modulus	200,000 MPa
Poisson's Ratio	0.3

Table 1. Material properties.

Solid Structure Analysis

The simulation in this paper is studied in Static Structural modulus of ANSYS workbench. In order to obtain deformations of the structure, the utilized principal elastic equation is as follows.

$$\{\sigma\} = [E]\{\varepsilon\}$$

In general, real materials respond differently in regards to the force directions. As this mat-ter, different modulus of elasticity is defined in each direction. In order to use orthotropic material properties, the elastic matrix must be defined precisely in lateral and longitudinal directions of the mandible. The following equation shows the parametric orthotropic material matrix for this problem.

$$[E]^{-1} = [S] = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}$$

Regarding to the previous assumption in literature, and are the same and the ma-trix in Eq (2) is simplified. By meshing the whole geometry for every node matrix, Eq (2) is deter-mined and by using Eq (1) stress and strains in each nodes are determined and the system is com-pletely solved.

Forces and Boundaries

In order to precisely model the mandibular jawing force, lots of studies are done to capture the mean biting force of human mandible. The bite forces are different from person to person. The difference is related to the individuality of jaw muscles. The muscles are different in genders, age and also the health of the whole jawing system which includes the teeth, mandible and the related muscles [10]. Related to these studies, in this paper, the mean bite force of 120 N is used to model after surgery situations where the patient cannot bite hard materials. The end of the cortical bone of the mandible is fixed in the software as demonstrating in Figure 10.

Results

In (Figures 11-19), the extracted results are shown. The first set of photos are related to the total deformation of the cortical bone and plates and screws (Figure 11, Figure 14, Figure 17), the second set is related to Von-Misses stress of the mandible of the fixation tools (Figure 12, Figure 15, Figure 18) and the third set is related to corresponding strain of the analysed structure (Figure 13, Figure 16, Figure 19).

As shown in the above Figures, each fixation method is studied precisely. In table 2, the cor-responding extracted results are shown. In the one-plate fixation, the mandible is looser and the maximum deformation is as expected higher than other methods. Regarding the maximum defor-mation column, the Triangular method is the most fixed method which the mandible deformation is ten times lower than plate and screw methods and therefore has lower strain. Also, in the Triangular method, the stress in the cortical bone is lower than the other methods. In comparison to one and two-plate methods, although the deformation of the one-plate fixation is higher, the stress born by the mandible and the fixation tools is lower and in the two-plate fixation, due to its firm grip of the cortical bone by the fixation tools, the regarding stresses are much higher.

Fixation Type	Deformation (m)		Stress (Pa)		Strain	
	Min	Max	Min	Max	Min	Max
One-Plate	0	9.513 E-5	56.36	7.88 E+7	3.1 E-10	0.00203
Two-Parallel	0	8.653 E-5	0	15.5 E+7	5.5 E-16	0.00256
Triangular Screw	0	0.6706 E-5	301.78	3.05 E+7	2.01 E-9	0.000017

Table 2. Different fixation method comparison.

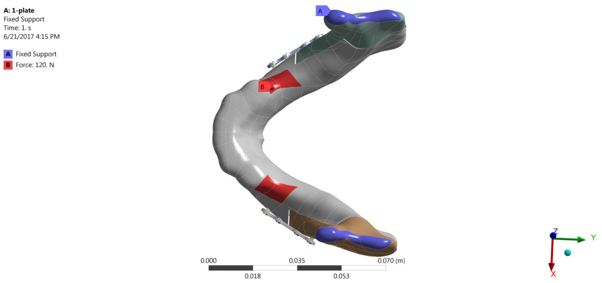

Figure 10. The Fixed support and force location on the mandible.

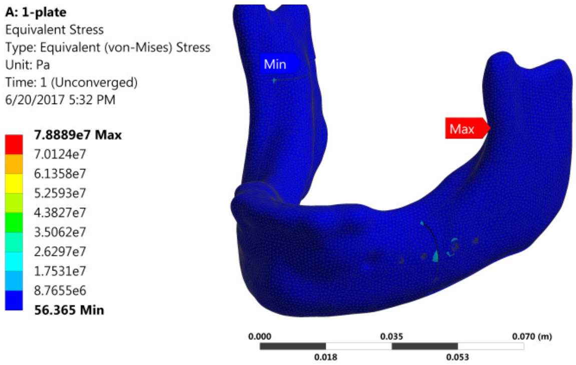

Figure 12. The one-plate fixation, stress contours.

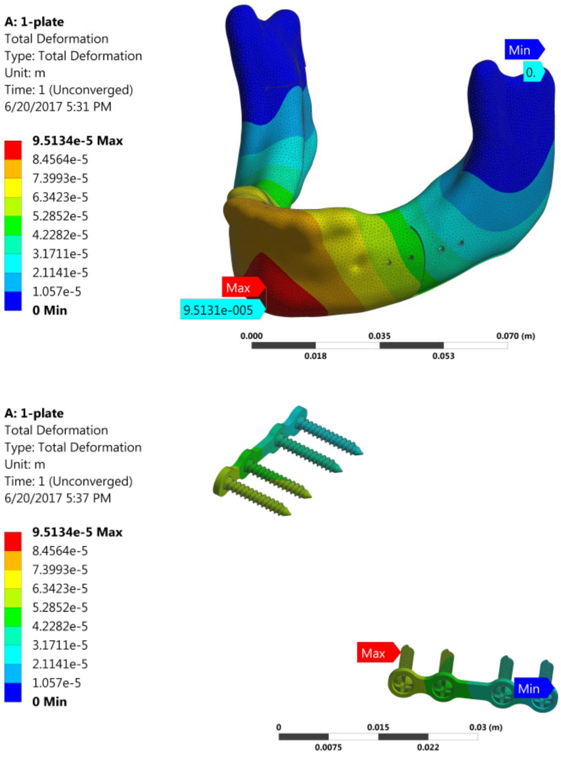

Figure 11. The one-plate fixation method, deformation Contours.

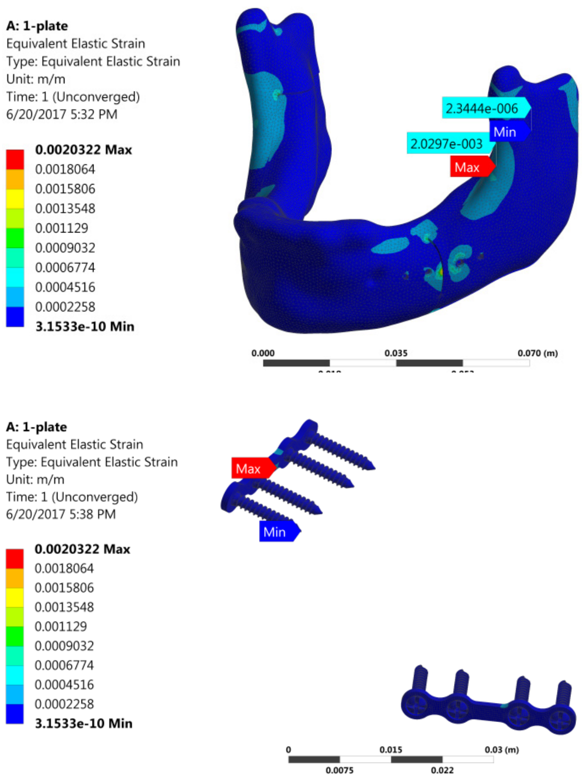

Figure 13. The one-plate fixation, strain contours.

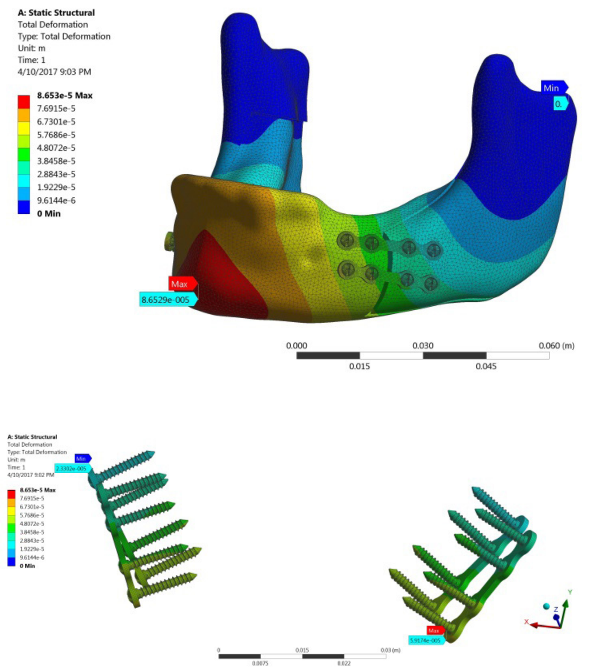

Figure 14. The Two-Parallel Fixation Method, Deformation Contours.

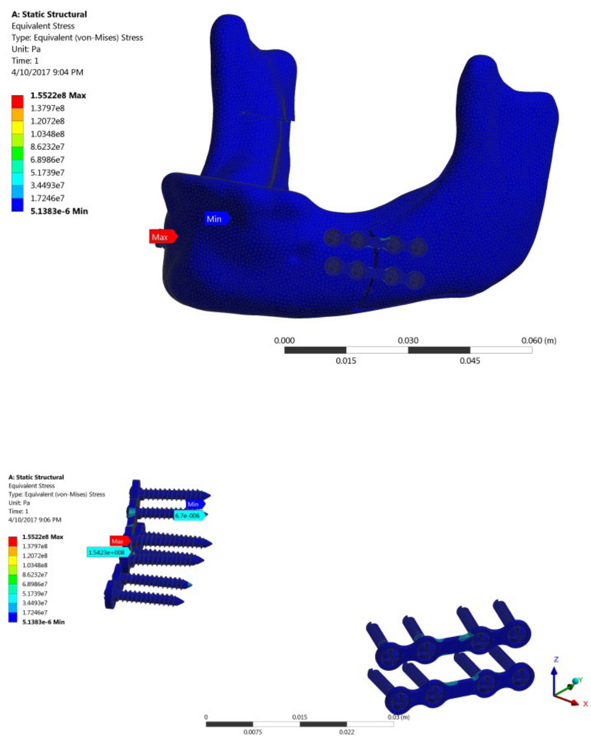

Figure 15. The two-parallel fixation method, stress. contours.

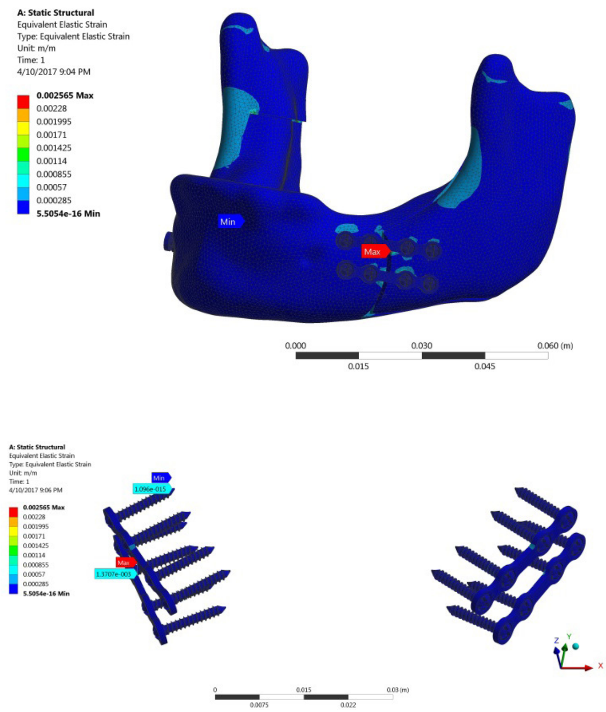

Figure 16. The two-parallel fixation method, strain contours.

Triangular Screw

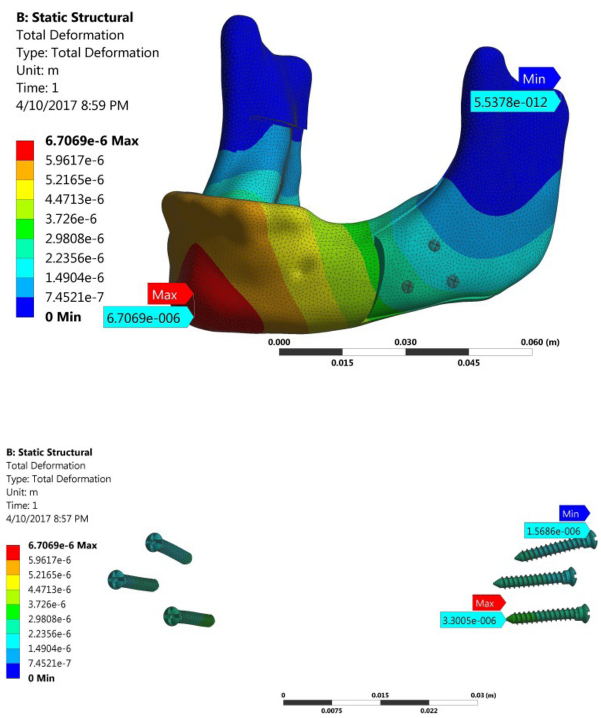

Figure 17. The triangular screw fixation method, deformation contours.

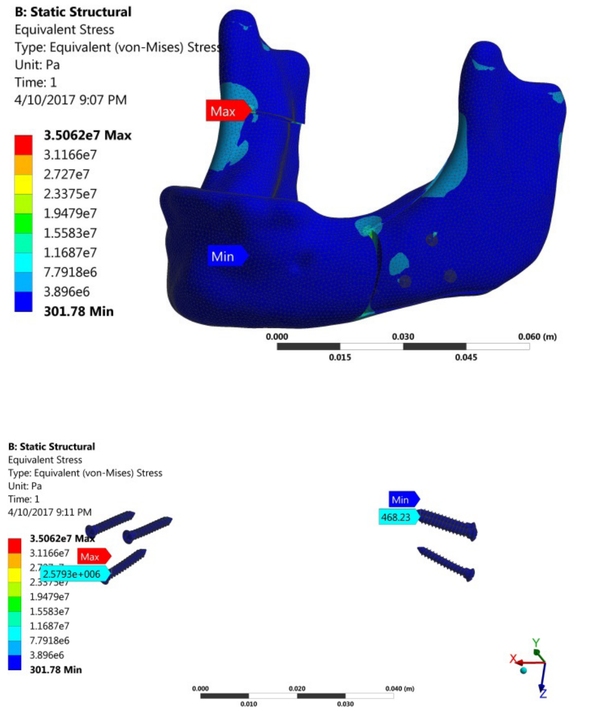

Figure 18. The Triangular Screw fixation Method, Stress Contours.

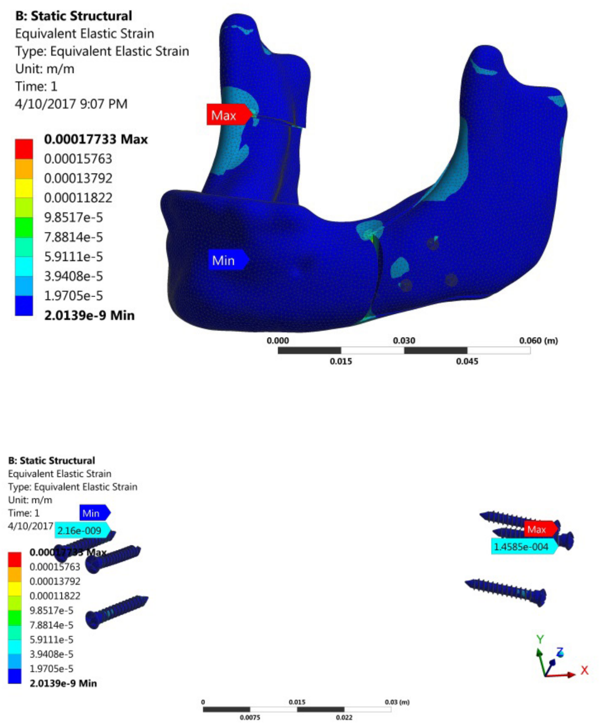

Figure 19. The Triangular Screw fixation Method, Strain Contours.

Conclusion

In this paper, the full mandible is modelled and three different fixation methods are analyzed precisely. By using Triangular screw fixation technique, a good stability can be achieved; the total deformation and stress in Triangular screw fixation technique are lower in comparison with two other methods. This type of technique reduces the surgery time, lessens the infection after the sur-gery due to less exposure and less external tools, and also, since the stress is lower in this method, the healing process is boosted and the patient suffers less during the rehabilitation.

Conflict of Interest

There is no conflict of interest to declare.

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Please cite this paper as:
Ghorashi M, Keshavarzi M, Damercheli Sh, Parhiz A; The comparison of three different fixation methods on bilateral sagittal split ramus osteotomy mandibular on a 3D of fully modelled mandible by the finite element method. J Craniomaxillofac Res 2019; 6(3): 113-121