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Original Research

Effect of using different methods of plate fixation in maxillary Lefort one fractures

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ABSTRACT

Objective: Maxillary fracture is the most prevalent fractures of the face. The aim of this study is to evaluate efficiency and disadvantages of different types of plate fixation in maxillary Lefort 1 fracture by using finite element analysis.

Methods: Three-dimensional model was reconstructed from Cone-Beam-tomography (CBCT) for finite element analysis. Then the fracture fixed by 4 methods of using L-type mini-plates or two-hole mini-plates in the Piriform or Zygomatic buttress. Forces were applied to measure the stress on the plates, screws, adjacent bone and the movement in the bony segments in 2 patterns of Bite force; Incisal clenching (INC) and intercuspal position (ICP).

Result: The maximum amount of stress was seen on the screws, plate-bar and bone adjacent to fracture line. These amounts were measured 29Mpa & 33Mpa consequently in type B (four 4-hole L shape) plate fixation in ICP and in type A (four 2-hole) plate fixation in INC patterns of Bite forces. However, the maximum amount of movement was observed in type A of plate fixation and the most stable method was Four L- shape plate fixation, the differences between stresses and movements in different fields of evaluation were not significant.

Conclusion: It can be concluded that there were no significant differences in these 4 types of plate fixation to show any superiority in clinical application.

1. Introduction

The protrusive position of maxillary bone predisposes it to fracture more than the others bone in the face [1,2]. The first goal of fracture treatment is to limit or stop the bone movements and prevent from complication such as ununion or malunion bone healing, infection or life threating abscesses [3]. There are various methods to fix the bone blocks [4–6], but the most proper method presented is the internal fixation with plates and screws [7–10].

Nowadays, using Lefort 1 osteotomy became more common to correct midface deformities and it can improve facial contour, omission asymmetries and improve patient's occlusion [11–13].

In long term successful surgical corrections, the important parameters are the amount of maxillary advancement and type of fixation (shapes, sizes and pattern of mini-plates) [12,14–17]. Some surgical methods such as fixation period extension, osteotomy modification, mini-plate utilization and iliac crest grafting are demonstrated to prevent maxillary relapse [12–18].

Finite element method appraises biomechanical characteristics of three-dimensional model generated from the original biologic model [19–21]. So this software represents every reaction in the environment like physic, dynamic and etc. the engineers and the doctors or the dentists can predict their deficiency or authority of their method or product [22,23].

So, in this article, we evaluate efficiency of 4 types of plate fixation in the maxillary lefort one fracture in two patterns of Bite force; Intercuspal position (ICP) and Incisal clenching by applying forces on the plates, screws, adjacent bone and the fracture segment to measure resulted stress and movement of bony segments in different spatial dimensions by using the finite element analysis to find the efficient method of fixation with the least post-operative morbidity.

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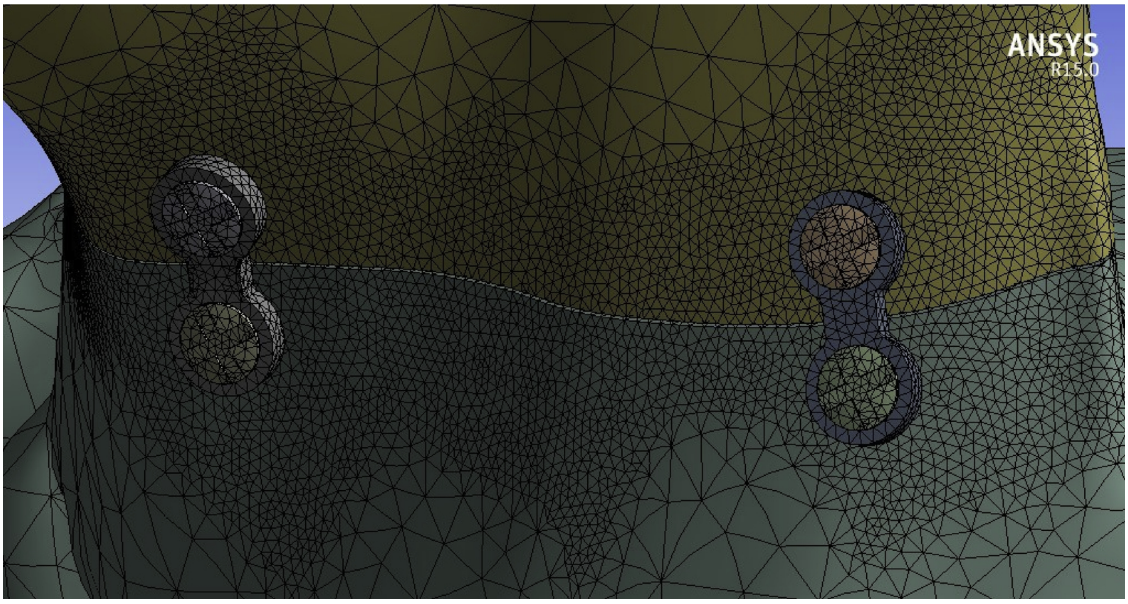

Fig. 1. Depended on type of the models, about 101,600 elements and 182,100 nodes were used.

Table 1
mechanical properties of simulated materials in study.

	properties	
Material	Yong modulus (GPa)	Poisson ratio(v)
Titanium	125	0.34
Dentine	17.6	0.25
Cortical bone	13.7	0.3
Cancellous bone	0.793	0.3

Table 2
Maximum stress von mises entered on the screws in Lefort l fracture in types of plate fixation (A, B, C, D) after using different patterns of Bite force: INC, ICP. (the measurements are calculated in Megapascal).

Pattern of Bite force Type of plate fixation	ICP	INC
A	24 Mpa	33 Mpa
B	29 Mpa	32Mpa
C	28.1 Mpa	28.3 Mpa
D	16 Mpa	22 Mpa

Table 3
Maximum stress von mises entered on the bone around the screws in Lefort l fracture in types of plate fixation (A, B, C, D) after using different patterns of Bite force: INC, ICP. (the measurements are calculated in Megapascal).

Pattern of Bite force Type of plate fixation	ICP	INC
A	5.8 Mpa	7.6 Mpa
B	5.4 Mpa	7.2 Mpa
C	9.2 Mpa	9.7 Mpa
D	9.1 Mpa	9.2 Mpa

Table 4
Maximum stress von mises entered on the plates in Lefort l fracture in types of plate fixation (A, B, C, D) after using different patterns of Bite force: INC, ICP. (the measurements are calculated in Megapascal).

Pattern of Bite force Type of plate fixation	ICP	INC
A	24 Mpa	33 Mpa
B	29 Mpa	32 Mpa
C	28.1 Mpa	28.3 Mpa
D	16 Mpa	21 Mpa

Table 5
Maximum movement of maxillary segment in Lefort l fracture in vertical dimension in different types of plate fixation (A, B, C, D) and patterns entering Bite forces (INC, ICP).

Pattern of Bite force Type of plate fixation	ICP	INC
A	0.173 mm	0.174 mm
B	0.15 mm	0.12 mm
C	0.164 mm	0.162 mm
D	0.161 mm	0.14 mm

2. Method and materials

2.1. Maxillary arch model generation

The CBCT imaging (New Tom V6i, QRS.r; Verona, Italy) achieved from the maxilla of 20 to 30 years old patients referring to Department of Oral and Maxillofacial Surgery of Jundishapur university of Medical Sciences, Ahvaz, Iran. All images had axial section with 0.3 mm thickness, 0.3 mm spaced and 512*512 pixel. Randomly, a CBCT image of patient with normal dentition and class one occlusion, absence of craniofacial abnormalities, pathologic lesions, and history of trauma was selected. The selected sample consisted of 419 sections, each section

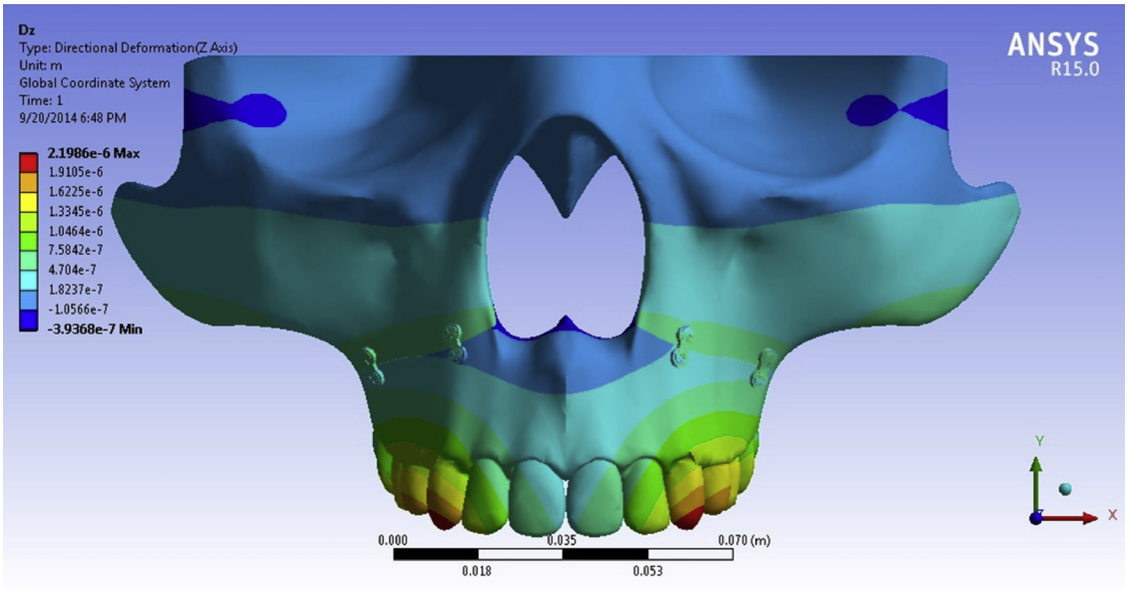

Fig. 2. measure of movement at anteroposterior dimension in type A of plate fixation in ICP pattern of Bite force.

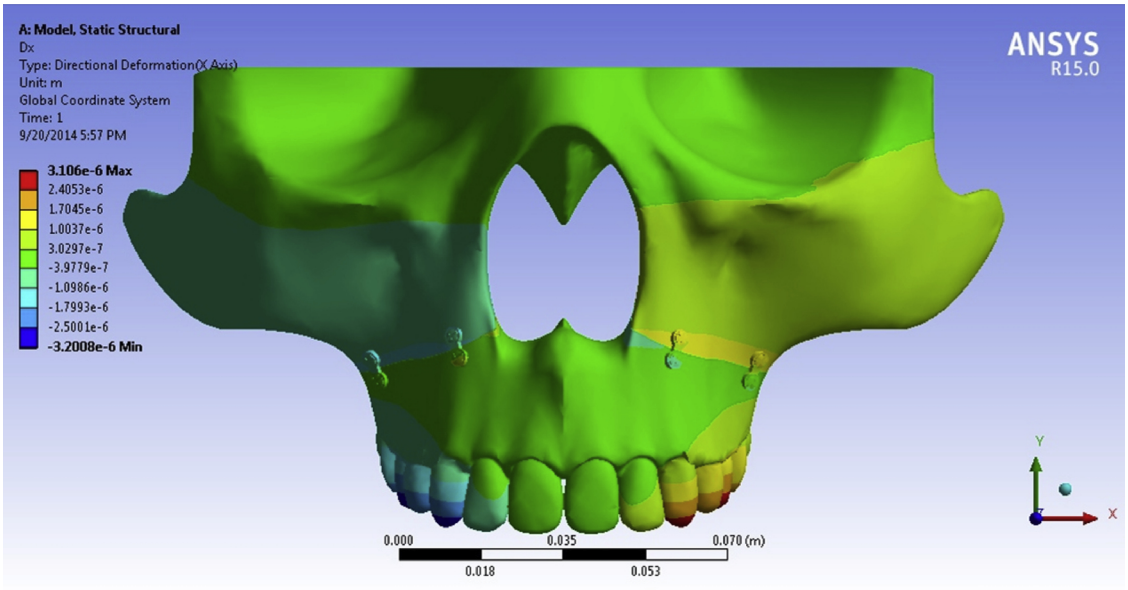

Fig. 3. measure of movement at mediolateral dimension in type A of plate fixation in ICP pattern of Bite force.

Table 6
Maximum movement of maxillary segment in Lefort l fracture in antero- posterior dimension in different types of plate fixation (A, B, C, D) and patterns entering Bite forces (INC, ICP).

Pattern of Bite force Type of plate fixation	ICP	INC
A	0.043 mm	0.101 mm
B	0.017 mm	0.0104 mm
C	0.039 mm	0.038 mm
D	0.085 mm	0.036 mm

stored as separate DICOM file and then transferred to the Mimics ver.16.0 software (Materialize b.v, Leuven, Belgium).

In order to increase the accuracy of the models, the reconstruction of the sagittal, axial, and coronal planes was done manually. Images of teeth, cortical bones and spongy bones were separated and classified. Considering the teeth to be attached to the cortical bone, by insertion of the pieces together, the model was renovated using stereolithography (STL). Then superficial ragged nesses were removed to prevent every probable error in software during applying the force. To constructing the 3D geometric solid surfaces, the computed model of maxilla that

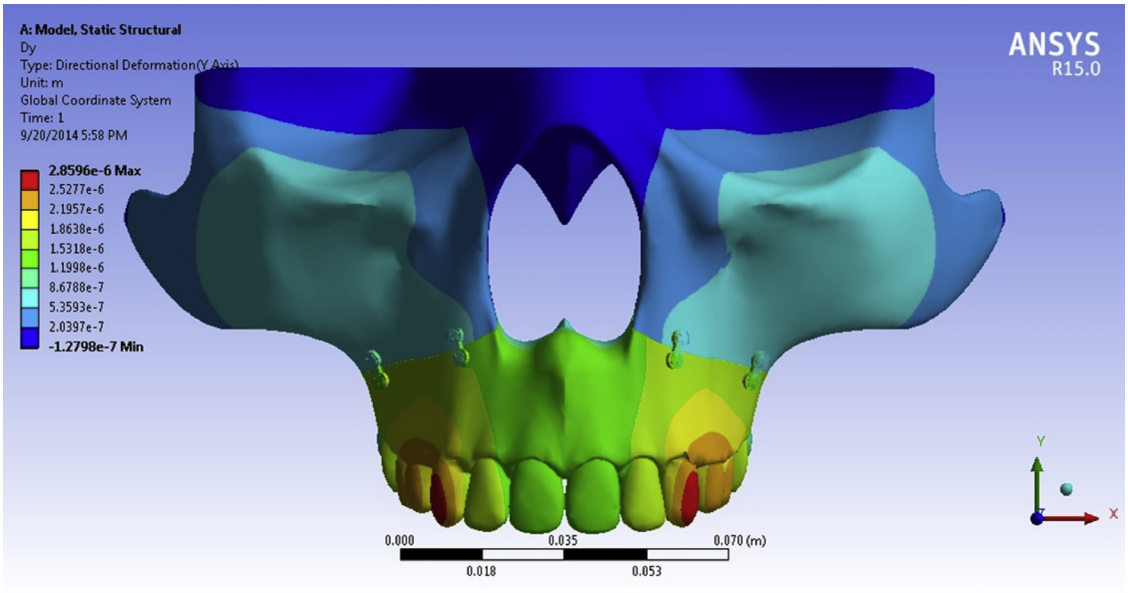

Fig. 4. measure of movement at vertical dimension in type A of plate fixation in ICP pattern of Bite force.

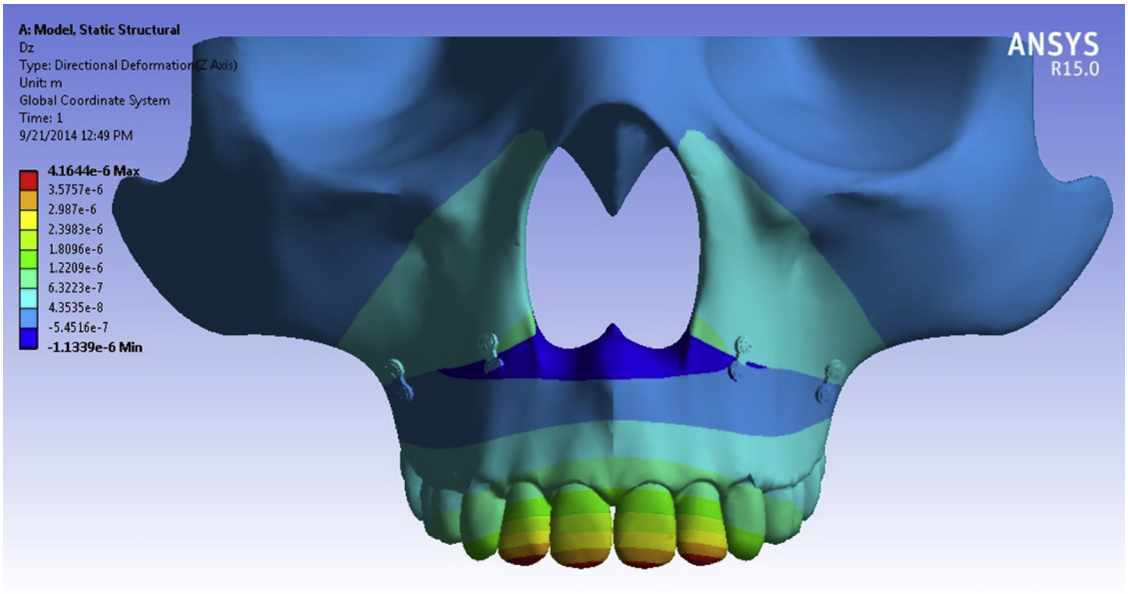

Fig. 5. measure of movement at anteroposterior dimension in type A of plate fixation in INC pattern of Bite force.

Table 7
Maximum movement of maxillary segment in Lefort l fracture in medio-lateral dimension in different types of plate fixation (A, B, C, D) and patterns entering Bite forces (INC, ICP).

Pattern of bite force Type of plate fixation	ICP	INC
A	0.054 mm	0.13 mm
B	0.023mm	0.0011 mm
C	0.032 mm	0.0098 mm
D	0.047 mm	0.0086 mm

cortical, spongy and teeth were separated was given to a 3-Matic 6.0 software (materialize b.v, Leuven, Belgium).

2.2. Screws and miniplates model generation

Using SolidWorks CAD 2012 (Dassault systems solid works Corp, Canada), mini plates and screws were modeled, bone sections provided, and mini plates/screw assemblies on slices were Implemented. The mini plates and screws produced by SYNTHES (Synthes Gmbh Eimattstrasse CH-4436, oberdorf, Switzerland) were used as samples in this project.

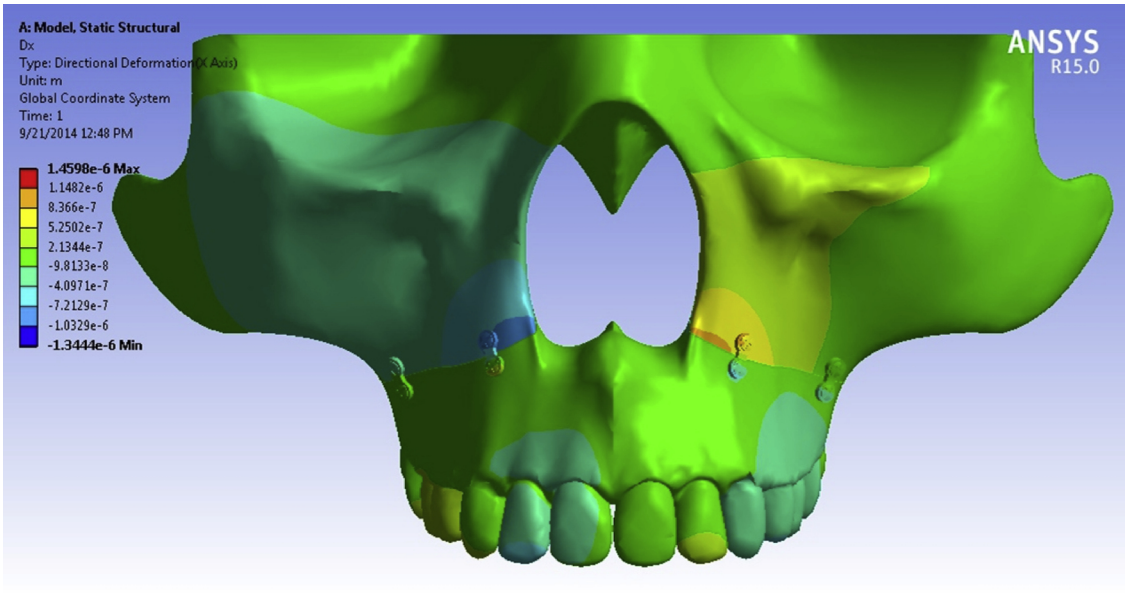

Fig. 6. measure of movement at mediolateral dimension in type A of plate fixation in INC pattern of Bite force.

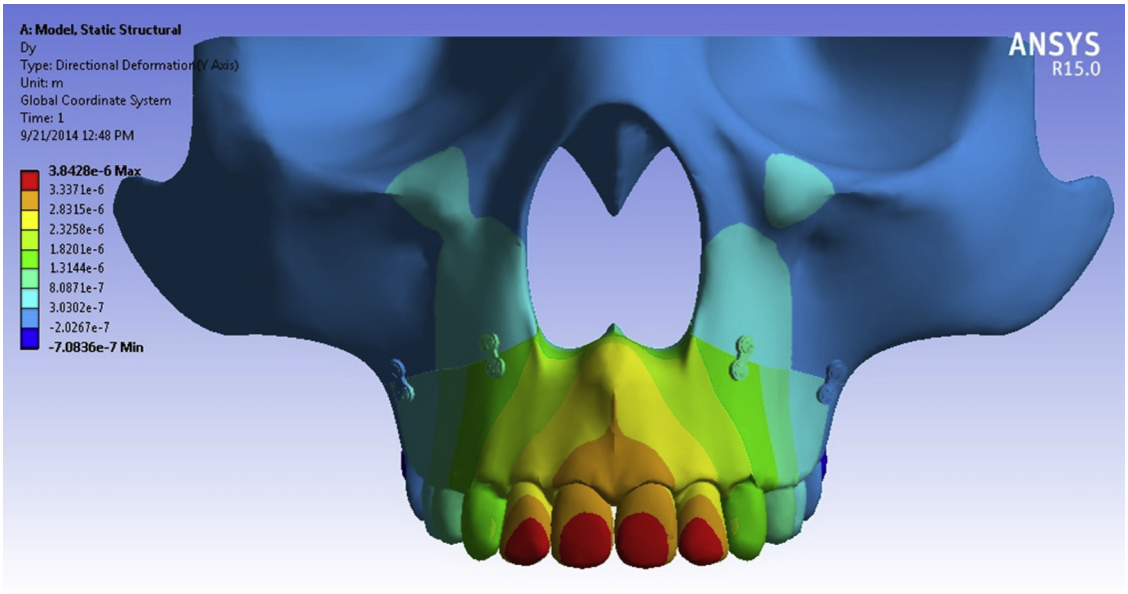

Fig. 7. measure of movement at vertical dimension in type A of plate fixation in INC pattern of Bite force.

L- type mini-plates with 1 mm thickness and length of 24 mm and 2-hole mini-plate with 1 mm thickness and length of 12 mm were designed similar to the origin model. screws considered like cylinder without threads with 2 mm diameter and length of 6 mm to prevent any mistake about concentration of stress on sharp edges of screws achieved by the software.

2.3. Various types of plate placement simulation

A. 2 two-hole mini-plates in maxillary pyriform and 2 two-hole mini-plates in buttress in both sides.

B. 2 L type mini-plates in maxillary pyriform and 2 L type mini-plates in maxillary buttress in both sides.

C. 2 L type mini-plates in Maxillary pyriform and 2 two-hole mini-plates in Maxillary buttress in both sides.

D. 2 two-hole mini-plates in Maxillary pyriform and 2 L type mini-plates in Maxillary buttress in both sides.

The maxilla, plates and screws models were constructed. To simulate Lefort one maxillary fracture an osteotomy with 0.5 mm thickness was created on the model. Then, miniplates were applied to the created cut based on four types of fixation (A, B, C, D) and the screws were inserted. Plates were adapted and fixed completely on the bone, so the

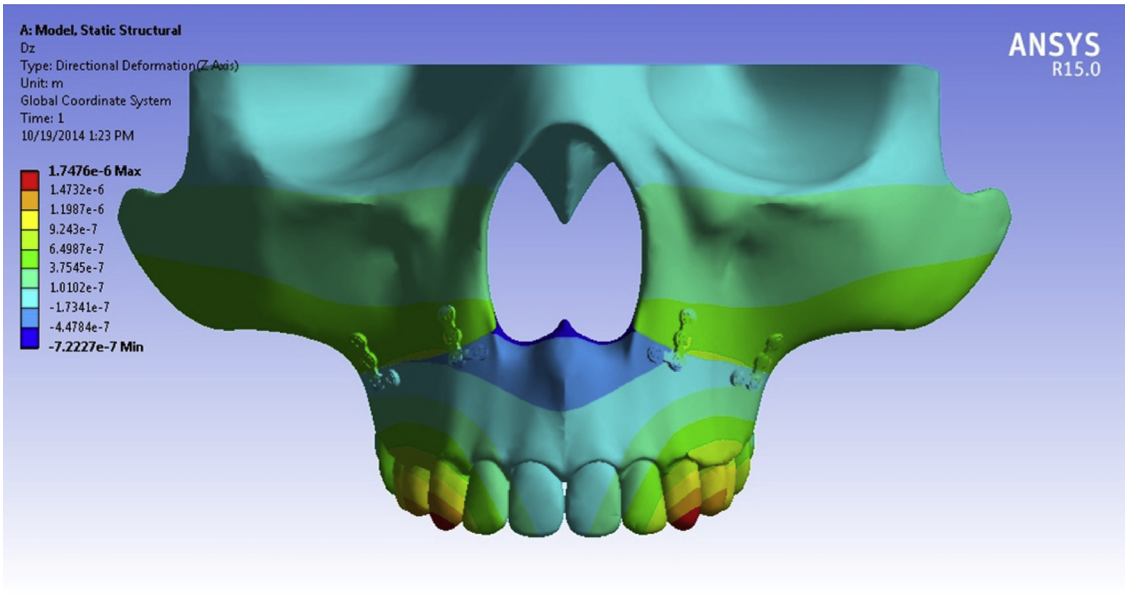

Fig. 8. measure of movement at anteroposterior dimension in type B of plate fixation in ICP pattern of Bite force.

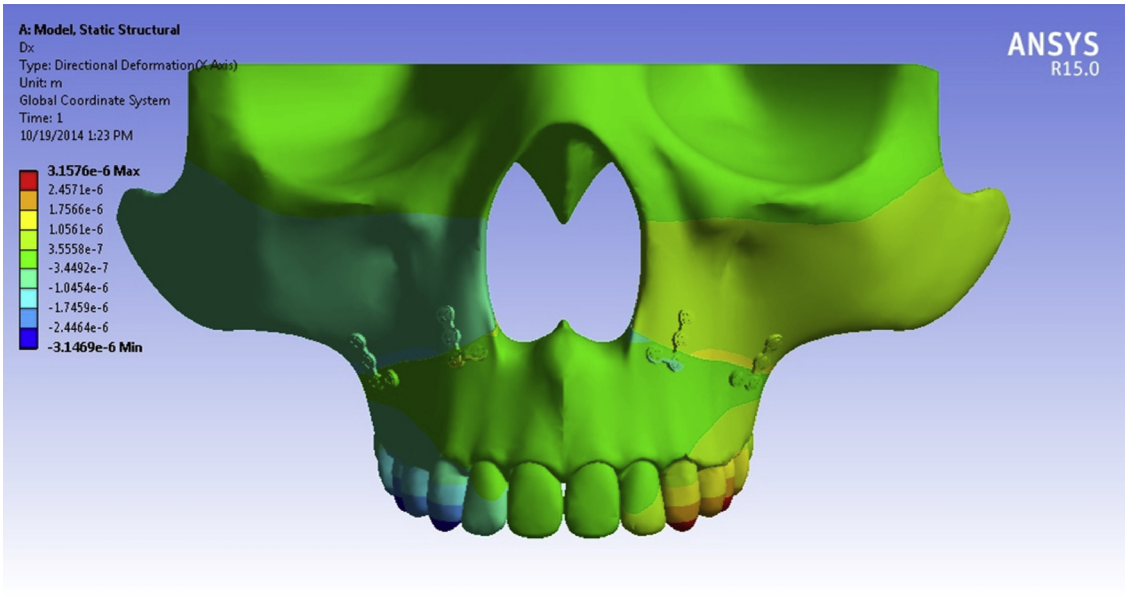

Fig. 9. measure of movement at mediolateral dimension in type B of plate fixation in ICP pattern of Bite force.

models obtained from model constructor software were imported to Abaqus version 6.12 software (Dassault systems, solid works Crop, Canada) to be analyzed. To increase accuracy, concentration of meshes in both sides of the fracture, plates and screws were increased. (Fig. 1)

Materials were considered Homogenous, with linear elastic feature, and isotropic. Mechanical properties of each material used in this study demonstrated in Table 1. In a position that the superior parts of the condyles were kept fixed on both sides and were only able to perform rotational movements, the Bite forces were simulated and applied using the Abaqus version 6.12 software (Dassault Systems, Solid Works Crop, Canada).

2.4. Patterns of bite force and simulation of loading

To reconstruct the patterns of Bite forces in Abaqus Ver 6.12 the superior part of the condyles was fixed and just the rotational movement done.

In this study, two patterns of Bite forces were considered:

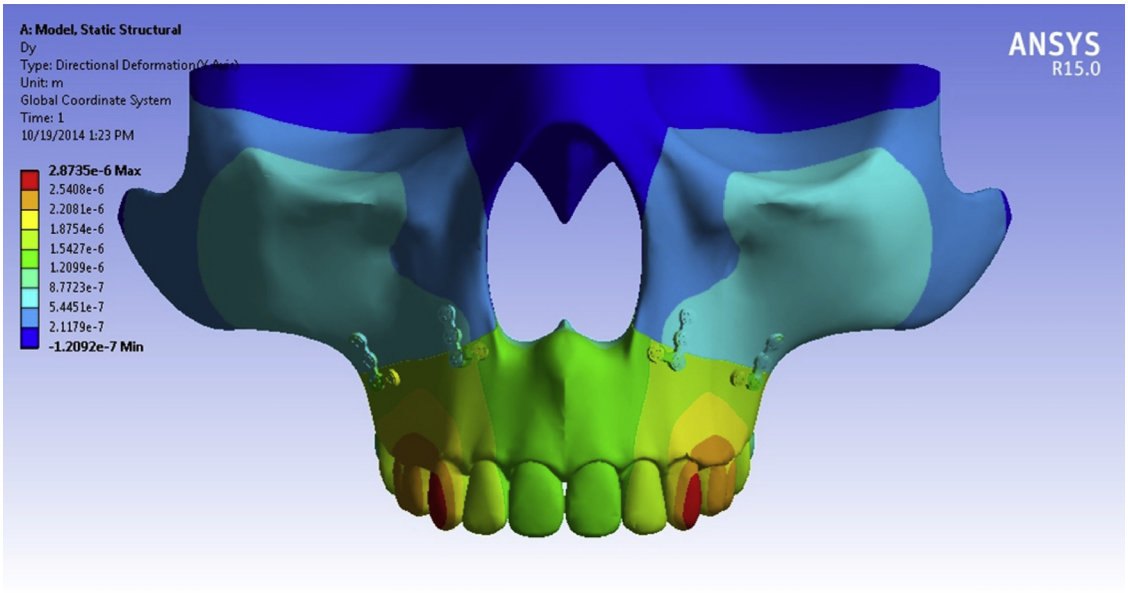

Fig. 10. measure of movement at vertical dimension in type B of plate fixation in ICP pattern of Bite force.

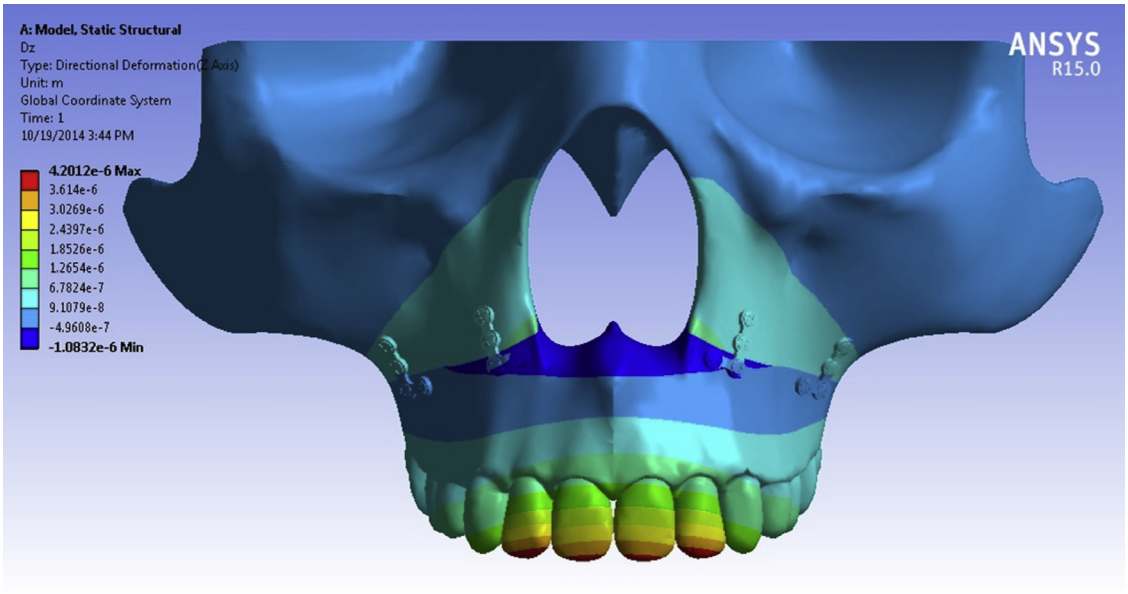

Fig. 11. measure of movement at anteroposterior dimension in type B of plate fixation in INC pattern of Bite force.

1.4. Clenching in the intercuspal position (ICP)

2.4. Incisal clenching (INC)

In the ICP pattern, 83 N should be applied to the teeth from canine to first molar on both sides. The applied force to canine and first premolar is twice in comparison with 2nd premolar and 1st molar. In the INC pattern, 26 N should be applied to 1st and 2nd incisor on the both sides. The applied forces to these teeth are the same.

Following the above steps, implementation of loading records in the same manner as previously described was done using Abaqus ver.6.12 software (Dassault Systems, solid works Crop, Canada). Pattern of distributing of forces, biomechanical stresses, amount in different patterns of Bite forces in healthy jaw, applied plates and screws on bone and area of fractures were considered. Also, the amount of movement in proximal and distal part of fracture were measured in every types of fixation.

As there is no effective muscle in the maxilla, the eventual muscle forces were abandoned.

The elastic limit of bending of medical titanium is 500 Mpa and

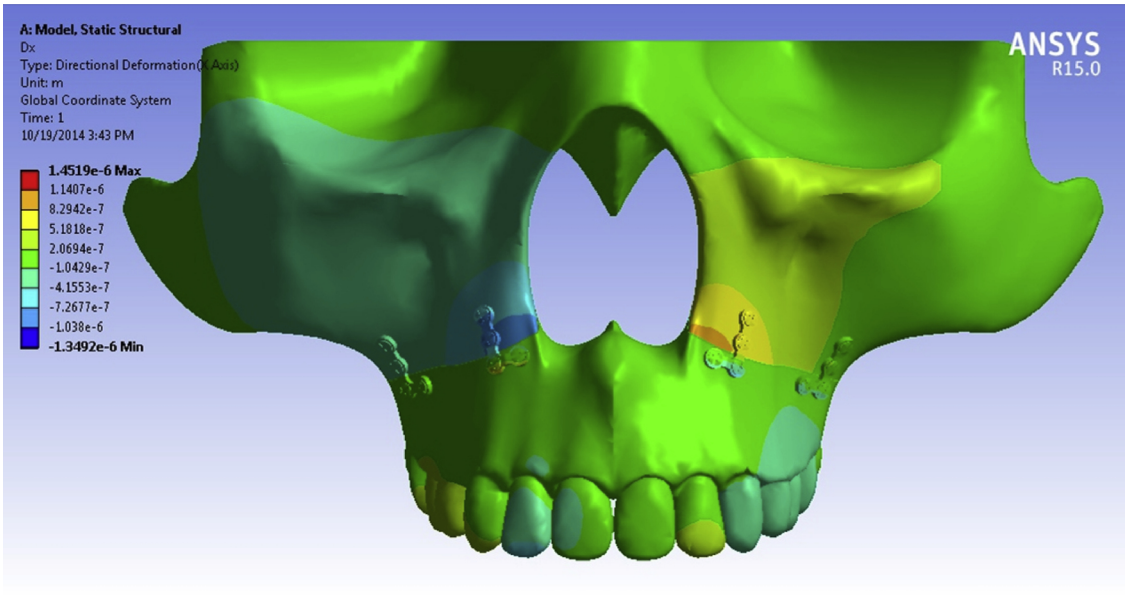

Fig. 12. measure of movement at mediolateral dimension in type B of plate fixation in INC pattern of Bite force.

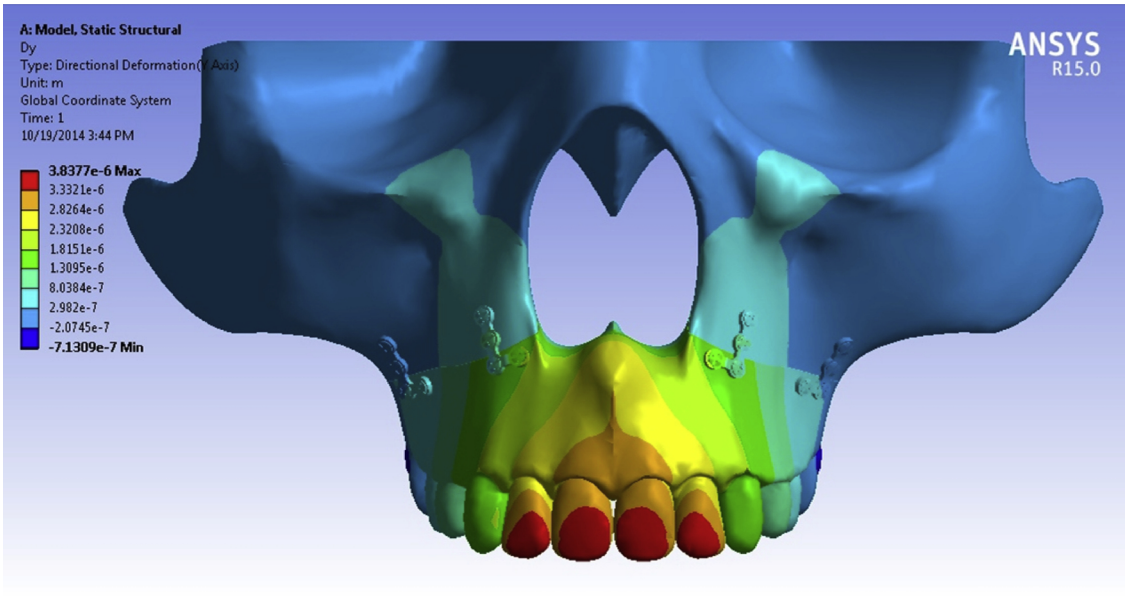

Fig. 13. measure of movement at vertical dimension in type B of plate fixation in INC pattern of Bite force.

static yield limit of that is 1000 Mpa. [24] The maximum toleration of compressive stress by bone is -50 Mpa, before bone resorption [25]. The acceptable range of movement between bony segments in different spatial dimensions is 0.300 mm before disturbance in bone healing [26].

3. Results

In this study, Lefort l fracture was considered in all of the patients and 4 types of plate fixation were evaluated in 2 patters of Bite force.

The analysis of Table 2 shows that in ICP pattern, the maximum of the stress entered on the screws was 29 Mpa belonged to B type of plate fixation and after that, subtraction of stresses respectively are C type,28.1 Mpa; A type, 24 Mpa and D type, 16 Mpa.

In INC pattern, the maximum of stress entered on the screws was 33 Mpa belonged to A type and after that, the deduction of stresses respectively, B type, 32 Mpa; C type, 28.3 Mpa and D type, 22 Mpa.

The analysis of the Table 3 shows that in ICP pattern, the maximum

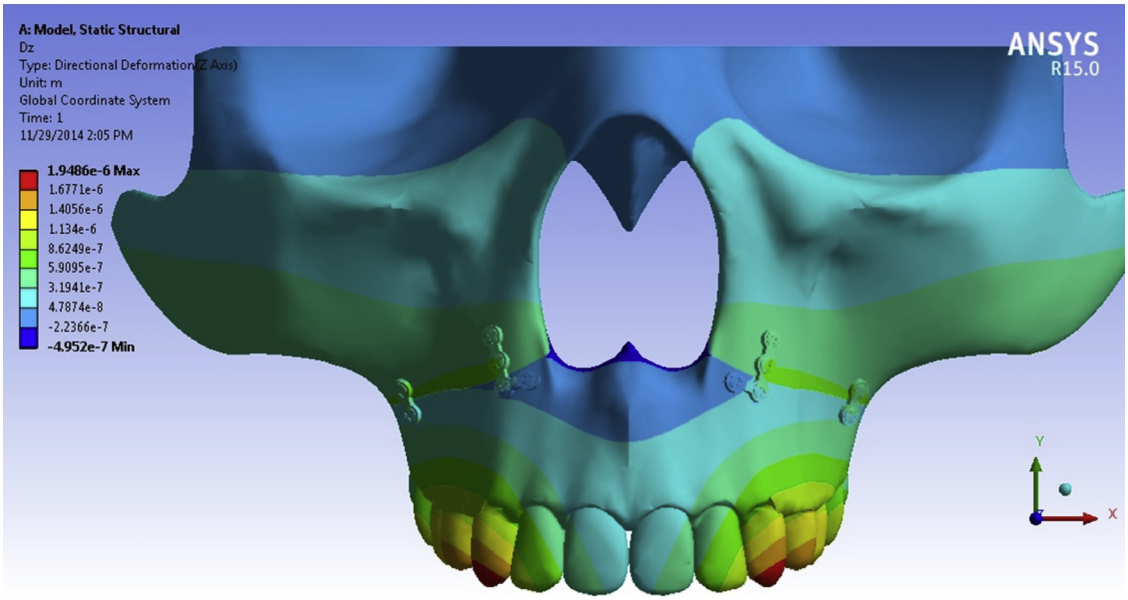

Fig. 14. measure of movement at anteroposterior dimension in type C of plate fixation in ICP pattern of Bite force.

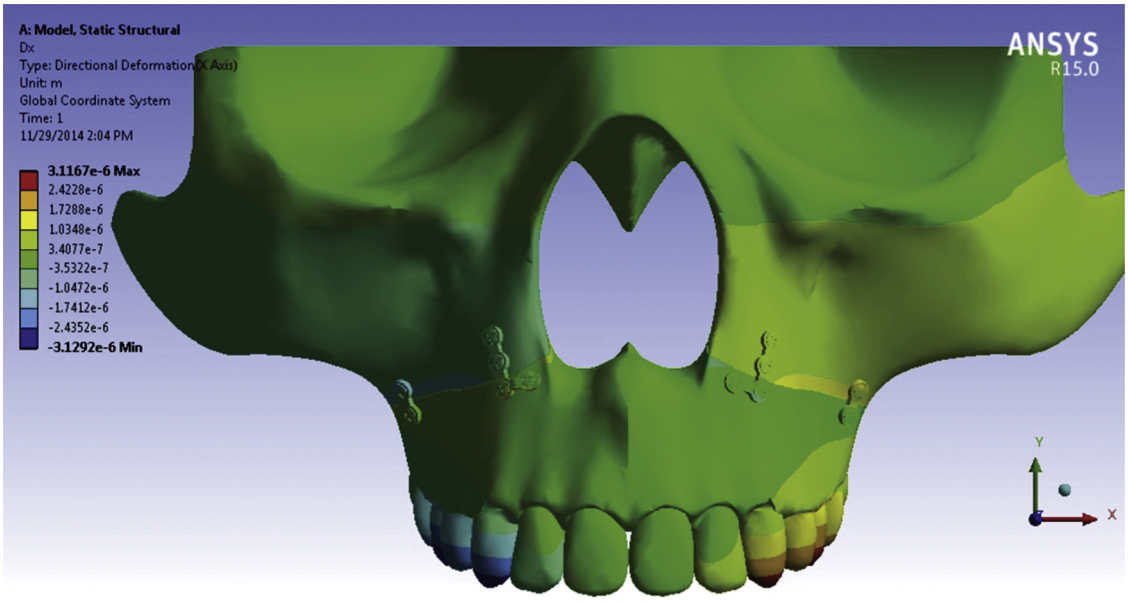

Fig. 15. measure of movement at mediolateral dimension in type C of plate fixation in ICP pattern of Bite force.

of the stress entered on the bone around the screws was 9.2 Mpa belonged to C type of plate fixation and after that, subtraction of stresses including D type, 9.1 Mpa; A type, 5.8 Mpa and B type, 5.4 Mpa.

In INC pattern, the maximum of stress entered on the bone was 9.7 Mpa belonged to C type and after that, subtraction of stresses respectively is, D type, 9.2 Mpa; A type, 7.6 Mpa and B type, 7.2 Mpa.

The analysis of the Table 4 shows that in ICP pattern, the maximum of the stress entered on the plates was 29 Mpa belonged to B type of plate fixation and after that, subtraction of stresses including C type, 28.1 Mpa; A type, 24 Mpa and D type, 16 Mpa.

In INC pattern, the maximum of stress entered on the plate was 33 Mpa belonged to A type and after that subtraction of stresses respectively are, B type, 32 Mpa; C type, 28.3 Mpa and D type, 21 Mpa.

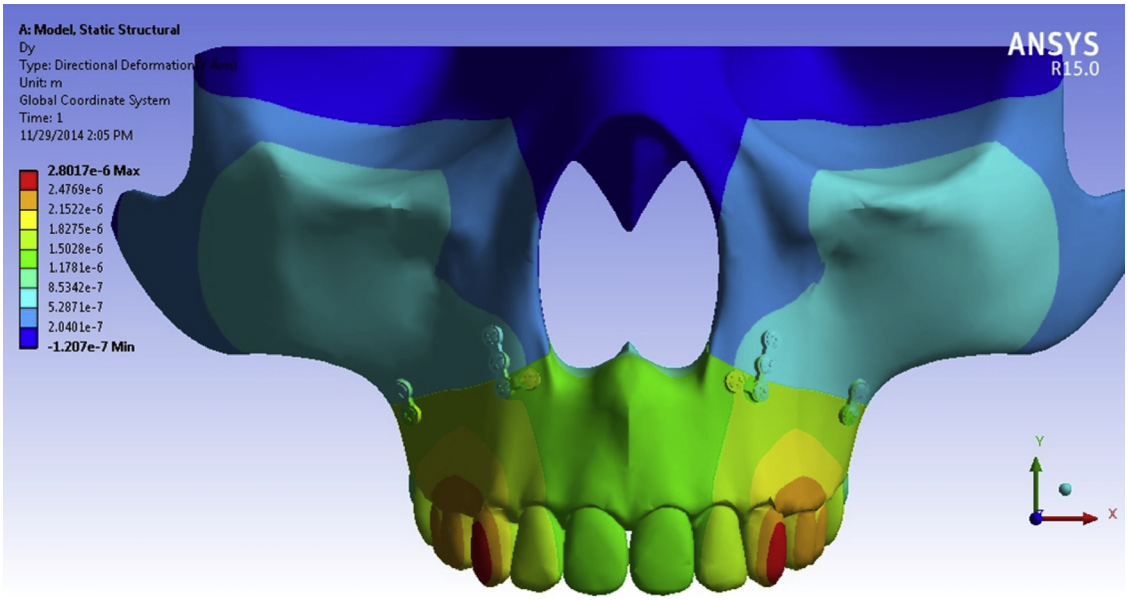

Fig. 16. measure of movement at vertical dimension in type C of plate fixation in ICP pattern of Bite force.

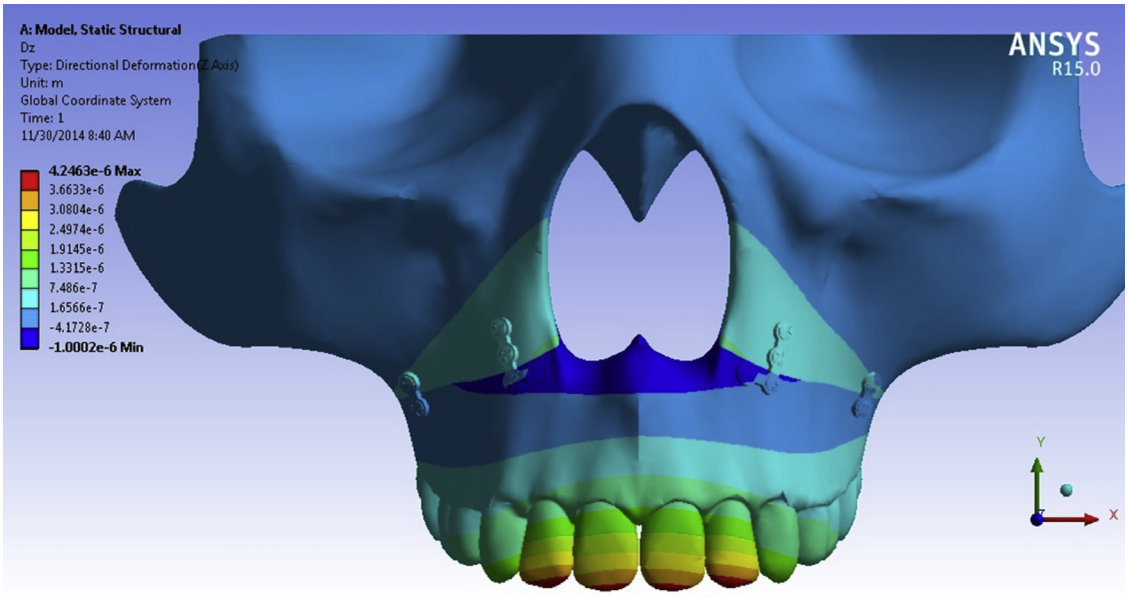

Fig. 17. measure of movement at anteroposterior dimension in type C of plate fixation in INC pattern of Bite force.

3.1. The amount of movement of the fractured maxillary segment in ICP pattern

The maximum measure of movement in vertical dimension was 0.173 mm belonged to A type of plate fixation (Table 5) and after that were C type, 0.164 mm; D type, 0.161 mm and B type, 0.15 mm. (Figs. 4,10,16,22)

The maximum measure of movement in antero-posterior dimension (Table 6) was 0.085 mm belonged to D type of plate fixation and after that were A type, 0.043 mm; C type, 0.039 mm and B type, 0.017 mm. (Figs. 2,8,14,20)

The maximum measure of movement in Medio-lateral dimension (Table 7) was 0.054 mm belonged to A type of plate fixation and after that were D type, 0.047 mm; C type, 0.032 mm and B type, 0.023 mm. (Figs. 3,9,15,21)

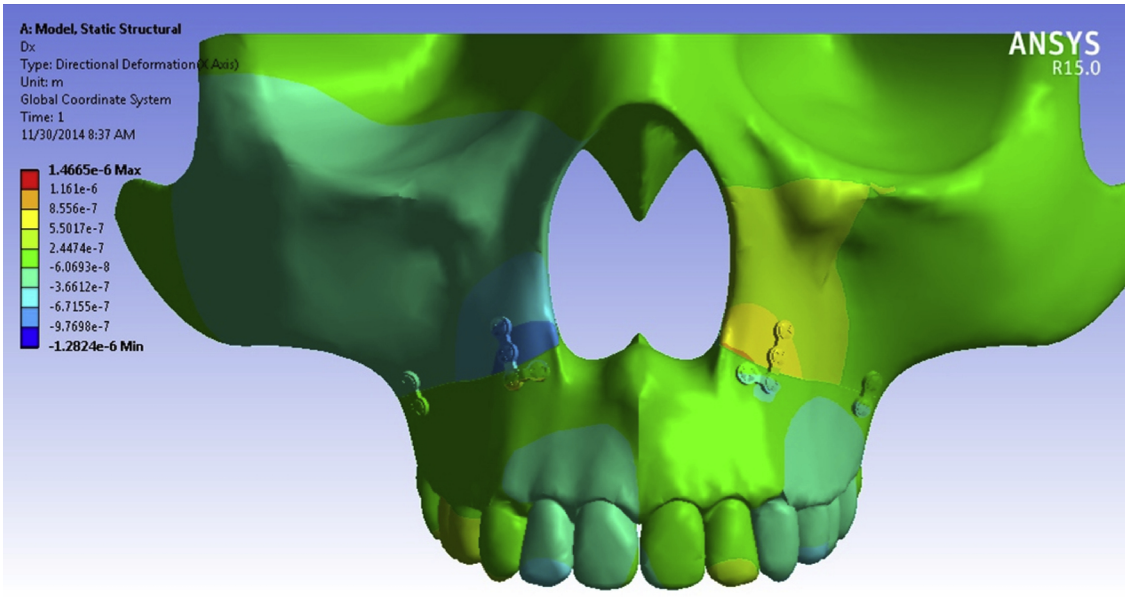

Fig. 18. measure of movement at mediolateral dimension in type C of plate fixation in INC pattern of Bite force.

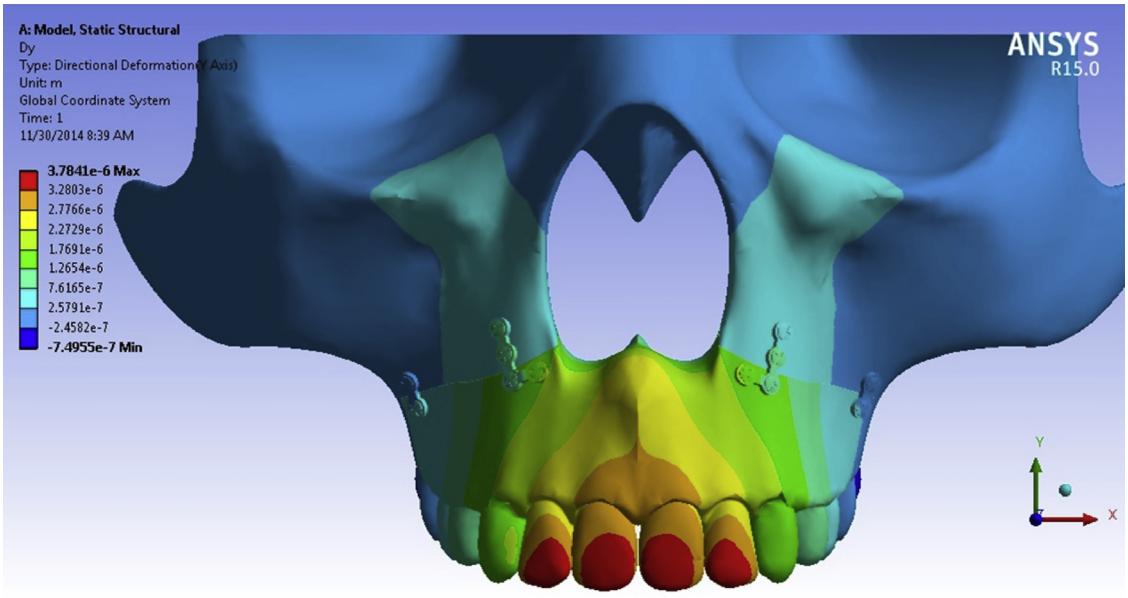

Fig. 19. measure of movement at vertical dimension in type C of plate fixation in INC pattern of Bite force.

3.2. In INC pattern

The maximum measure of movement in vertical dimension (Table 5) was 0.174 mm belonged to A type of plate fixation and after that were C type, 0.162 mm; D type, 0.14 mm and B type, 0.12 mm. (Fig. 7,13,19,25)

The maximum measure of movement in antero-posterior dimension (Table 6) was 0.101 mm belonged to A type of plate fixation and after that were C type, 0.038 mm; D type, 0.036 mm and B type, 0.0104 mm. (Figs. 5,11,17,23)

The maximum measure of movement in medio-lateral dimension (Table 7) was 0.13 mm belonged to A type of plate fixation and after that were C type, 0.0098 mm; D type, 0.0086 mm and B type, 0.0011 mm. (Figs. 6,12,18,24)

4. Discussion

There are so many methods have been introduced to fix the maxillary lefort one fracture [4–6]. The best and suitable method of them which is widely usable in these days is internal fixation using miniplates

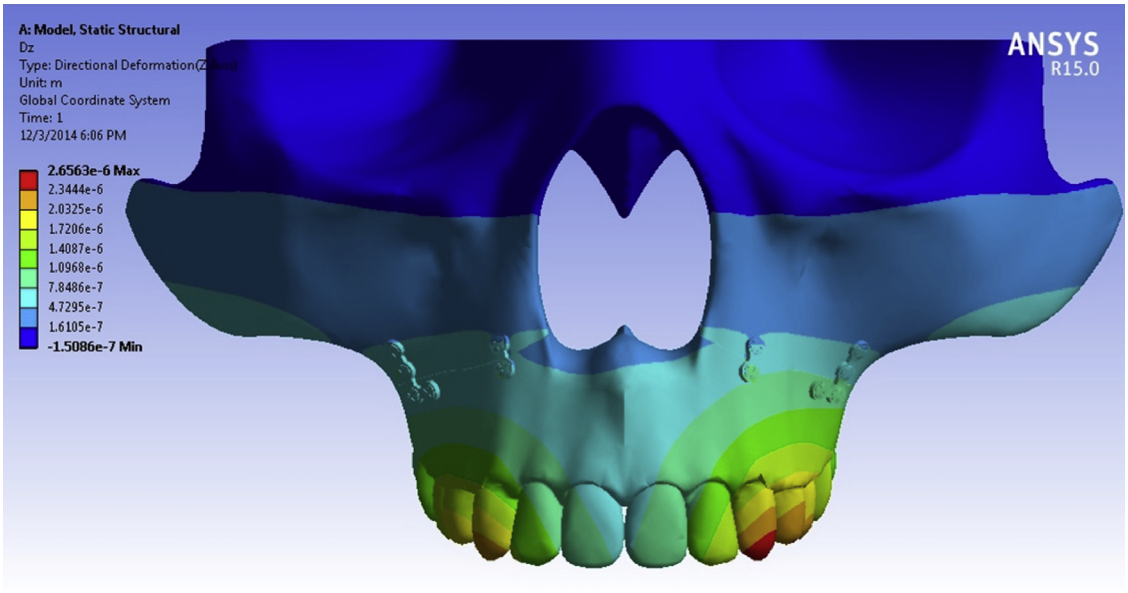

Fig. 20. measure of movement at anteroposterior dimension in type D of plate fixation in ICP pattern of Bite force.

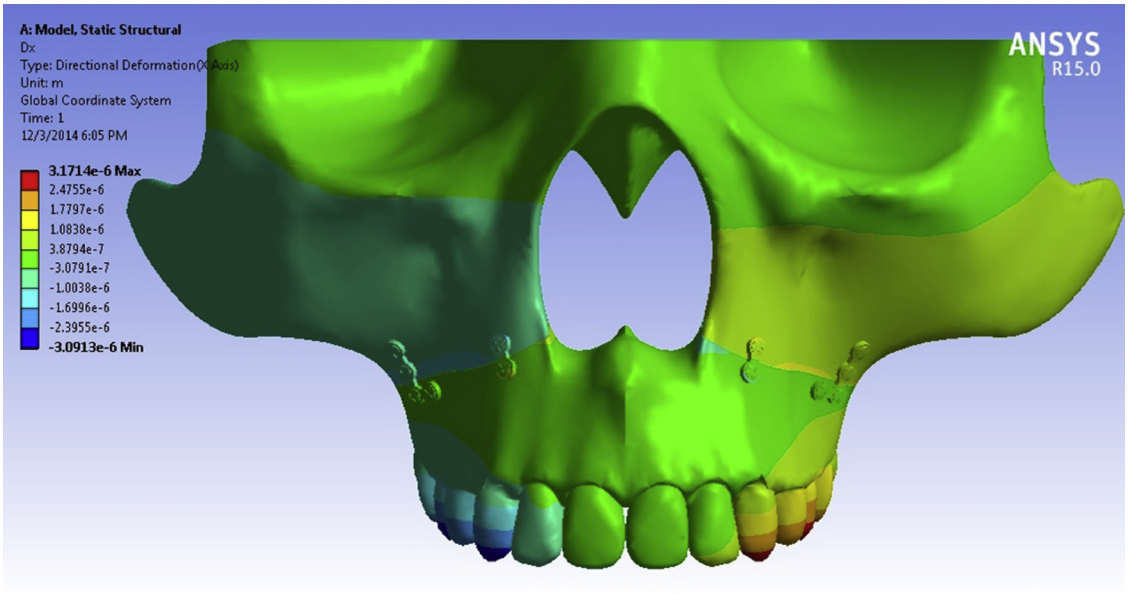

Fig. 21. measure of movement at mediolateral dimension in type D of plate fixation in ICP pattern of Bite force.

and screws [7,9]. This method has some advantages such as faster rehabilitation, patient's satisfaction, no necessity to inter-maxillary fixation (IMF) and improvement of occlusal relation [7]. The drawbacks of using a mini-plate in maxillary fractures are including screw loosening, bending or breaking the plates and etc. occurring in 20–25% of patients [27–34].

In this study, the models of stress distribution after applying two different Bite force patterns were the same in every type of osteosynthesis The maximum stress was concentrated in the holes near the fractured line, the bar of the plate, the screws near the fractured line, and in the neck of the screw. Oppositely, the minimum stress was on the screws and plate's holes which located far from the fractured area. Thus, the maximum compressive stress was measured in the bony hole where the screws was placed and it was more in INC pattern than ICP pattern in every type of fixation.

According to various studies, it can be argued that the most common complication associated with the use of screws and mini plates is the loosening of the screws, not the fracture of the mini plates [37]. Mechanical characteristic of medical titanium which used in plate and screws production, is important issue in clinical utilization. The amount of elastic limit of bending is about 500 Mpa [24,35,36]. Consequently, when less than 500 Mpa stress loads on titanium, it bends reversibly. In span of stress between 500–1000 Mpa, titanium bends irreversibly. It means, this amount of stress can result to bending of plate and screws

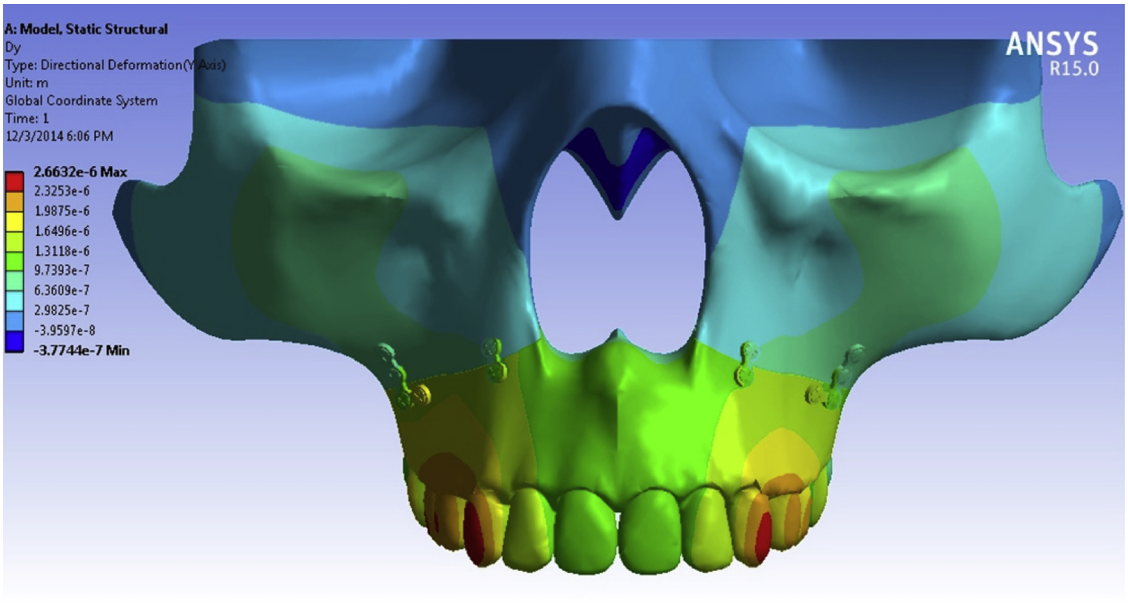

Fig. 22. measure of movement at vertical dimension in type D of plate fixation in ICP pattern of Bite force.

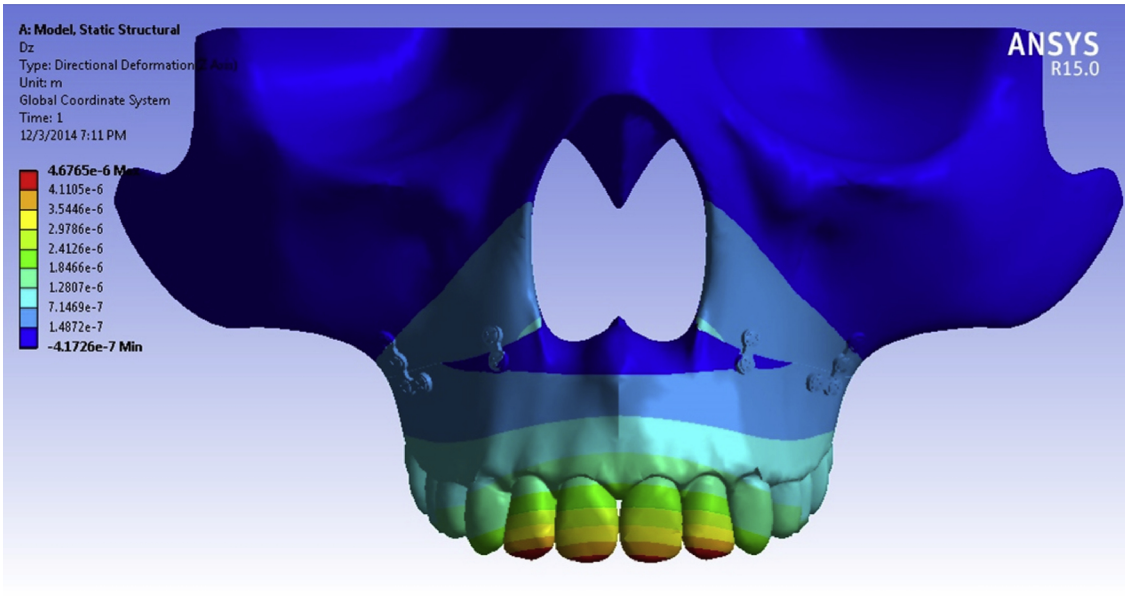

Fig. 23. measure of movement at anteroposterior dimension in type D of plate fixation in INC pattern of Bite force.

which consequently cause bony segments displacement and occlusion disturbance. Finally stress more than 1000 Mpa result in titanium fracture.

Biting force is one of the parameters which describe the masticatory system's efficiency [27]. FEA method which used in this study, evaluated the biting force with ethical consideration [16]. It has up to 99% accuracy in its results and several studies use this method to evaluate the force applied on the screws and miniplates in recent years [10,22,27,38].

In 2016, Huang et al. [12] evaluated the biomechanical interactions of different miniplate fixations and maxillary advancements in the Le-fort l osteotomy. Their result showed that the concentration of stress in bone located around the first screw hole above the osteotomy line in axial and oblique loads and the similar area were found at the bending region of the miniplates. This study recommends to use L-shaped miniplates with lateral fixation to provide better stability. miniplate fractures and maxillary relapse increases also, when maxillary advancement in Lefort l osteotomy become greater than 5 mm. These results almost are similar to this study.

In 2014, Wu et al. [39] used functional three-dimensional FEA model of bioabsorbable internal fixation and compared the stability of 5 methods of resorbable internal fixation devices application in maxillary Lefort l fracture. They analyzed the stability of fixations under four chewing pattern and they conducted that the fixation using two bioabsorbable plates was not stable and the Zygomaticomaxillary pillars fixation was more stable than the others. Also they resulted that the stress was concentrated close to the fracture line on the plates and near the intersection of screw and plate just as the results in this study.

The limitations of this study are no-reconstruction of TMJ and PDL, because they are so complicated to be reconstructed due to accessible

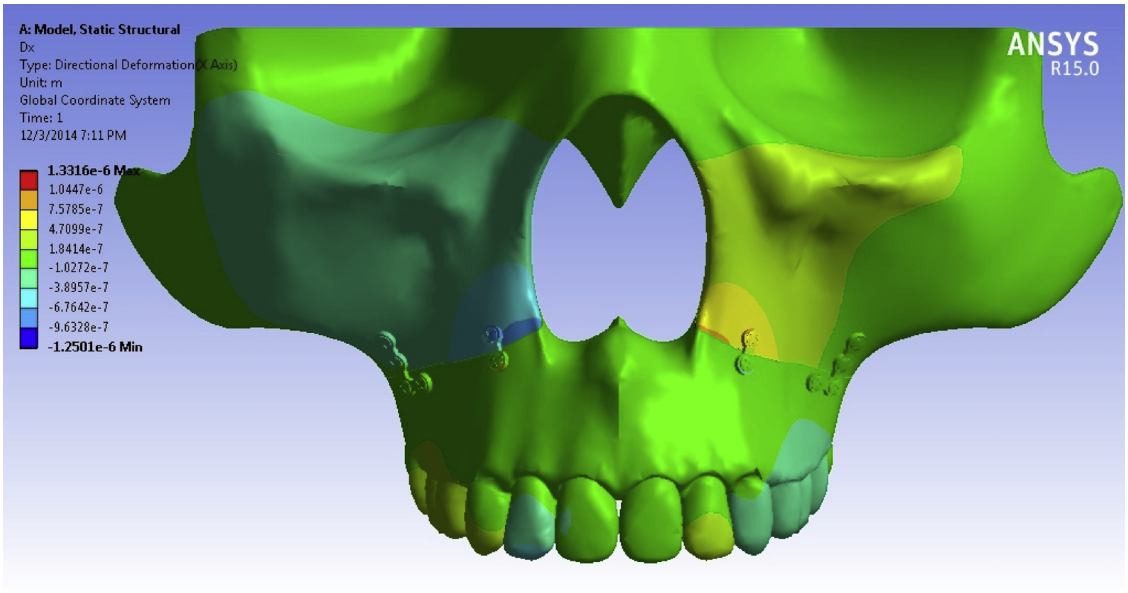

Fig. 24. measure of movement at mediolateral dimension in type D of plate fixation in INC pattern of Bite force.

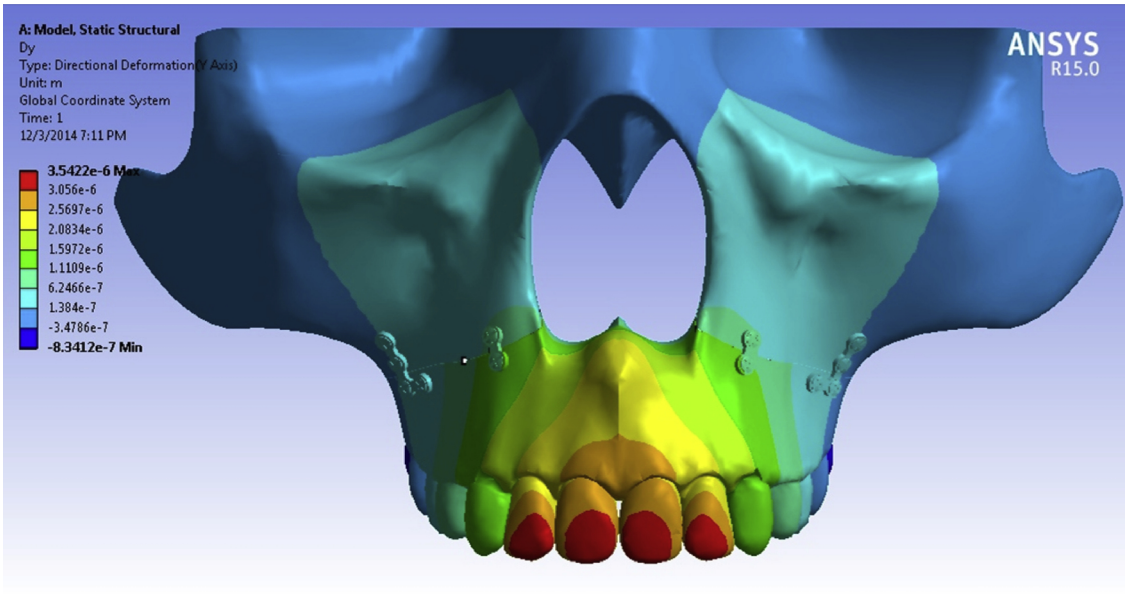

Fig. 25. measure of movement at vertical dimension in type D of plate fixation in INC pattern of Bite force.

facilities. None of the related articles evaluated them [35,37–45].

Despite of using precise finite element method, our result may vary from human's studies because in these methods the bone is considered homogenic which is not the same in the natural bone [44]. we recommend the similar study to evaluate the Lefort one osteotomy in different repositioning of the maxilla for treatment of different types of skeletal deformities.

According to four types of fixation and two pattern of bite forces, following results are considerable:

1. The maximum amount of stress was seen on the screws, plate-bar and bone adjacent to fracture line. So, precise bone drilling and secure screwing is suggested in particular near the fracture line.

2.This study showed that the most stable type of fixation was B type (in which 4 L-type miniplates were used) with a view to amount of fractured segment displacement in every three dimensions and every two patterns of occlusion (ICP, INC).

3.This study showed that the worst type of fixation was type A(in which 4 two-hole miniplates were used), because the maximum amount of bone movement in INC pattern in every three dimensions and in ICP pattern in two dimensions (vertical, medio-lateral) were the most.

4.The amount of fractured bone movement in every three dimensions in types C&D of fixation were almost similar.

5. However, the maximum amount of fractured segment's movement was observed in type A of plate fixation and the most stable method was Four L- shape plate fixation, this amount of movement cannot result in bony segment displacement and occlusal disharmony clinically.

6. The amount of stresses loaded on plates and screws and bone adjacent to screws were almost similar in every four types of fixation, so, it can be concluded that these four types of fixations in this study do

not have any significant differences in terms of stresses factors.

5. Conclusion

It can be concluded that there were no significant differences in these 4 types of plate fixation to show any superiority in clinical application. Considering that the stress is concentrates adjacent to the fractured line, so it is recommended to the surgical team to be more careful during the bone drilling and assured of precise screws' position, especially near the fractured line.

Declaration of Competing Interest

Authors of this manuscript have no conflict of interest that may damage the integrity of research.

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