Original Article

Study of the effect of the shape of the miniplate on the stability of mandibular symphyseal fracture using finite element analysis

Altaib Abdalrazik Mohammed

Department of Oral and Maxillofacial Surgery, Faculty of Oral & Dental Medicine, South Valley University, Qena, Egypt

ABSTRACT

Introduction: Finite element analysis is a new technology used for mechanical designing, and showing the behavior of the body when subjected to different loads as regards the resulted stresses and displacement.

Aim: The aim of this research was to detect the effect of the miniplate shape on stability of the mandibular symphyseal fracture.

Patients/Methods: Through this study two configurations of the miniplates were compared. The two miniplates are equal in length, width, thickness and of the same material, only they are different in shapes, one plate was straight and the other was L shaped, they are investigated using three dimensional finite element software.

Results: There was no significant difference between straight and L shaped miniplate, however the L shaped miniplate was slightly superior to straight miniplate as regard plate stability.

Conclusion: There is no significant difference between the different systems. The shape of miniplate may have a role in stability of mandibular fracture stability, the same plate shows different behavior when fixed at different positions double plate shows more stability than single one ,of the same shape finite element technology is helpful means for designing of different fixation systems.

Key Words: Biomechanics, finite analysis, plate shape, symphyseal fracture

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Corresponding Author: Altaib Abdalrazik Mohammed, Department of Oral and Maxillofacial Surgery, South Valley University, Qena, Egypt, **Tel.:** 01223046874, **E-mail:** altaib.mohamed@dent.svu.edu.eg, Kena20052006@yahoo.com

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INTRODUCTION

Mandibular symphysis is the most prominent part of the mandible and more liabe to fracture it represents 35% of mandibular fracture[1] due to surrounding conditions as muscle pull and bite force mandibular symphysis show complex biomechanics, the most prominent displacement was due to negative bending where there is compression at the superior border and tension on the lower border , also the most prominent torque through the mandible was discovered at the symphyseal region so any fixation system used to manage symphyseal fracture must resist the mentioned ,movements, according to the study of Tams *et al*.[2]

It was stated in the literature that fracture displacement should not exceed 150 μm for proper healing[3]. There are multiple factors affecting the stability of the fixation system as regards the dimensions, numbers and position of the fixation systems, however the study of the effect of the shape of plate on fracture stability was little through the literature.[4]

Also, there continuing biomechanical trials to simulate the biomechanics of the mandibular symphysis, recently three dimensional finite element analysis can be used to study the complex mandibular biomechainics.[5]

So that, the aim of this study was to determine the effect of the shape of miniplate on stability of mandibular symphyseal fracture using finite element analysis.

MATERIALS AND METHODS

The region of symphyseal fracture was simulated simply by sketching the fracture through an acrylic block which is 15 thickness and 40 in height as the same dimensions of the symphysis according to the study of Alkhateeb *et al*[6].

The titanium miniplate of straight shape and L was simulated having the same length (28 mm) and width (4mm) and thickness 1mm) also with the same diameter and number of holes (6 holes) the plate fixed to the acrylic bar using miniplate screw 2mm in diameter and 11 mm in length, each type of plate was simulated to fixate the fracture at different pattern as following:

1- single straight plate at the superior border(SSS)
2- single straight plate at the middle(SSM)

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3- single straight plate at the lower border(SSL)
4- single L shaped plate at the superior border(SLS)
5- single L shaped plat at the middle(SLM)
6--single L shaped plat at the lower border(SLL)
7- double straight plates one at the superior border and the other at the lower border(DS)
8- double L shaped plate one at the superior border and the other at the lower border(DL)

Each system was simulated in three dimensional finite element analysis software (Fusion 360 provided by AUTODISK) and the material properties was as shown in the Tables (1,2) and these properties derived from the library of the used software.

Table 1: showing material properties of titanium

Density	4.51E-06 kg / mm^3
Young's Modulus	102810 MPa
Poisson's Ratio	.3
Yield Strength	275.6 MPa
Ultimate Tensile Strength	344.5 MPa

Table 2: material properties of acrylic block

Density	1.188E-06 kg / mm^3
Young's Modulus	2740 MPa
Poisson's Ratio	.3
Yield Strength	48.9 MPa
Ultimate Tensile Strength	79.8 MPa

Boundary conditions

Each system was tested for negative bending by application of load 100 newton at the fracture site at the superior border while both distal surfaces on both right and left site were fixed for all directions (X, Y,Z) Also each system was tested for torque moment by fixation of the left distal surface and application of torque force 100 N on the right distal surface, the effect of friction of plates with the underlying substrate(acrylic bars), and also between the surfaces of the substrates at the fracture site was abolished by selection separation type of bond , so that the applied bite force transmitted from the acrylic bar to the fixed screw then to the plate then from the plate to the other acrylic bar on case of torque.

All the materials used throughout this study was isotropic and linear according to the study of Wang[7].

High convergence was done for all the results, as regards the von Mises stresses and displacement according to the study of Ayal and Ekmen[8]. The numbers of nodes and elements for the used models for the used models are presented in Table 3.

Table 3: number of nodes and elements of the used models

The model	Number of nodes	Number of elements
Model of the single straight miniplate	27970	17352
Model for the L shape miniplate	25149	15459
Model for the double straight miniplate	65336	42223
Model for the double L shape miniplate	62031	39640

RESULTS

As regards bending moments (Figures1-6)

Finite element analysis through this study depended on the displacement and stresses generated through the miniplates, on application of vertical bending load displacement occur on x,y,z directions the mean displacements through these directions were calculated and this is summerized through Table 4 and Figures 9-16 no model shows displacement more than 150 microns , both single straight and L shaped pate show the highest displacement at the lower boder however the displacement through the single L shaped plate was less than that single straight plate, double straight plate showed less displacement than both single straight and L shaped plate and this is obvious at the lower border plate.

While double L shape plate shows less displacement than double straight plate.

As regards the resulted von Mises stresses on bending measured in megapascal throught the miniplates, these stresses did not exceed the yield limit of titanium in all groups , the highest stress was noticed at the inferior border plates but single L shaped plate is less stressed than the single straight plate while lower border plate in double straight system showed less stress than single straight and L shaped single plate , as regards the double L shaped plate system showed the least stress of all systems either at the superior border plate or inferior border plates.

It is noted that as the bending stress increased gradually the displacement also increased in linear relation ship as shown on linear graph 1which demonistrates that single L shaped plate is more stable than single straight shaped plate, also double L shaped plate is more stable than double straight plates.

Fig. 1: Displacement on bending through single straight plate

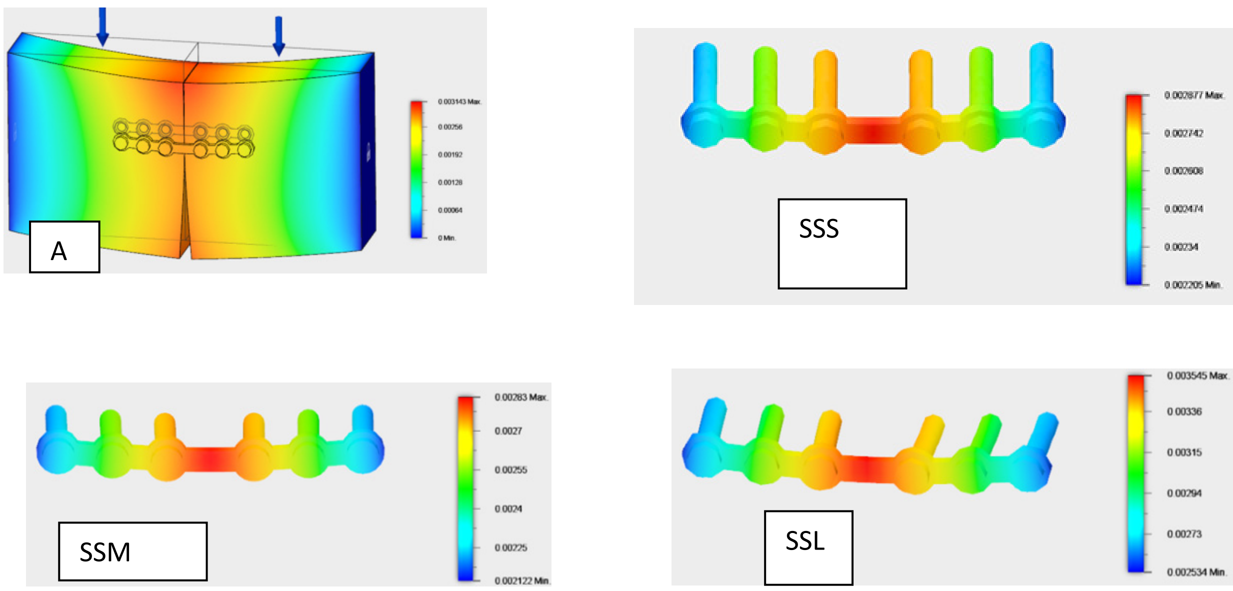


FIGURE showing displacement on bending through:
A-single straight plate at the superior border and surrounding region
SSS- -single straight plate atr the superior border
SSM- single straight plate at the middle
SSL0-single straight plate at the lower border

Fig. 2: Displacement on bending through single L plate

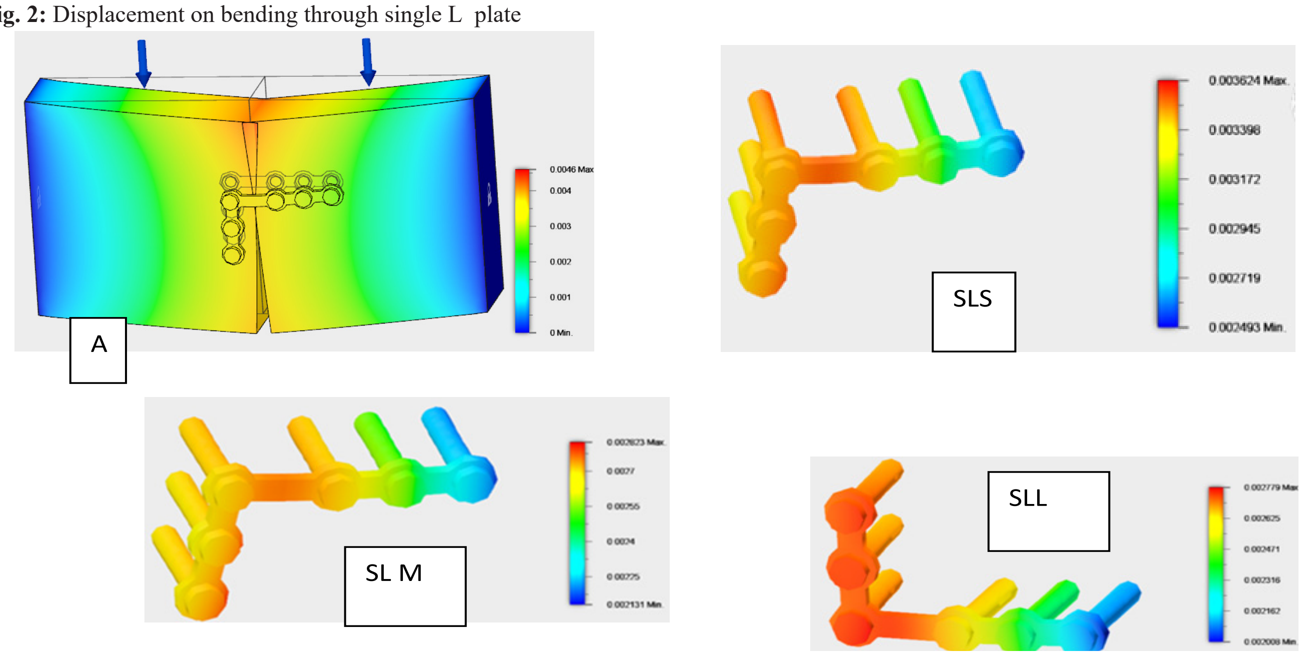


Figure showing displacement on bending through:
A-single l shaped plate on the superior border and surrounding region
SSS- single L shaped plate
SLM- single l shaped plate on the middle
SSL – SINGLE L shaped plate at the lower border

Fig. 3: Displacement through double straight and double L shape plate

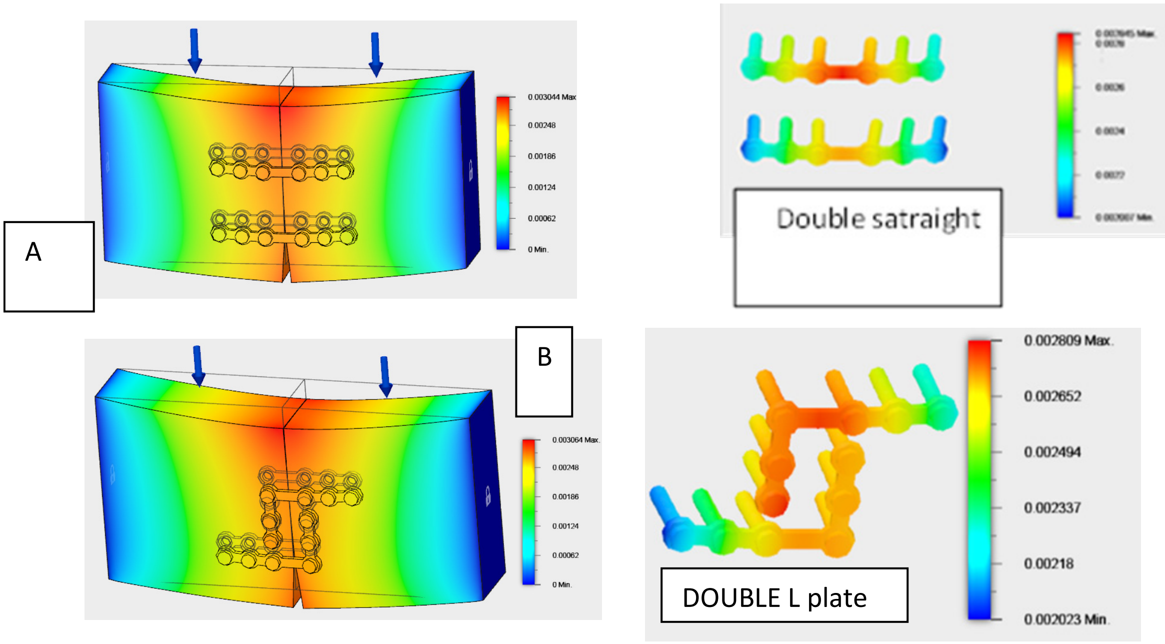
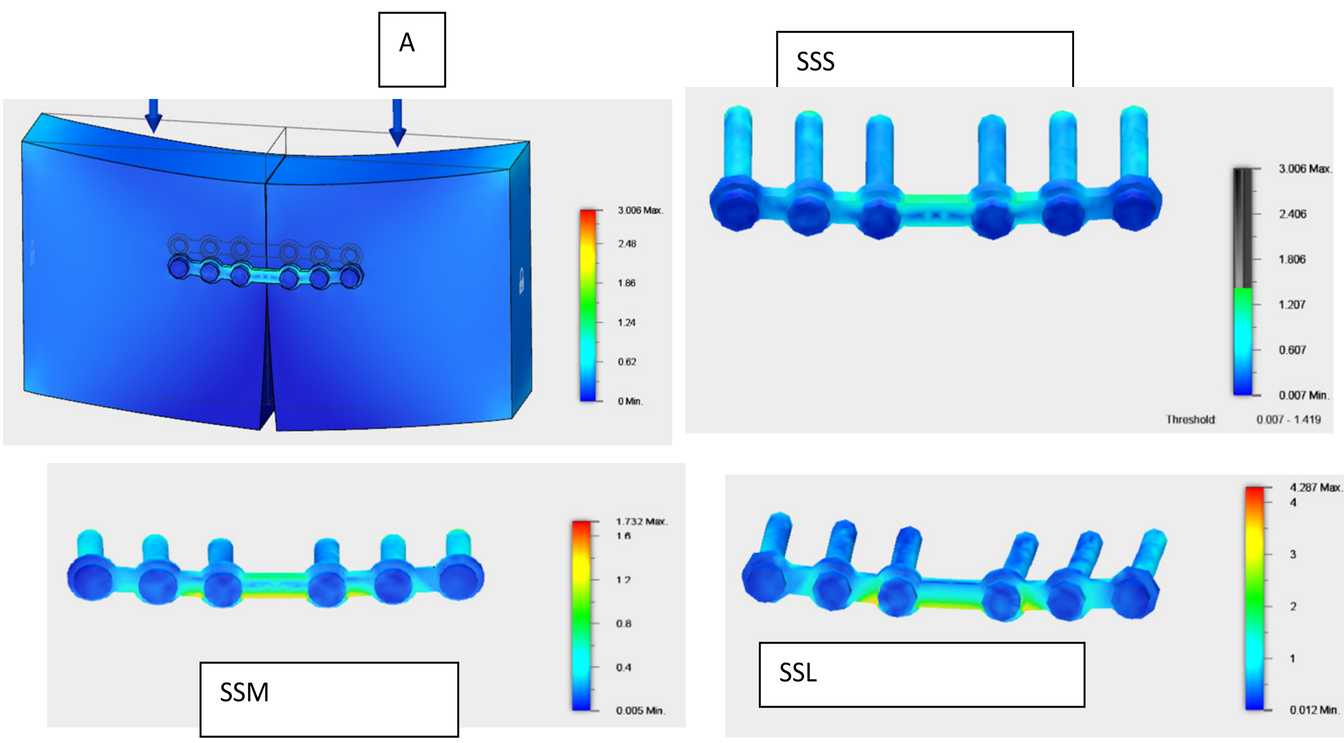


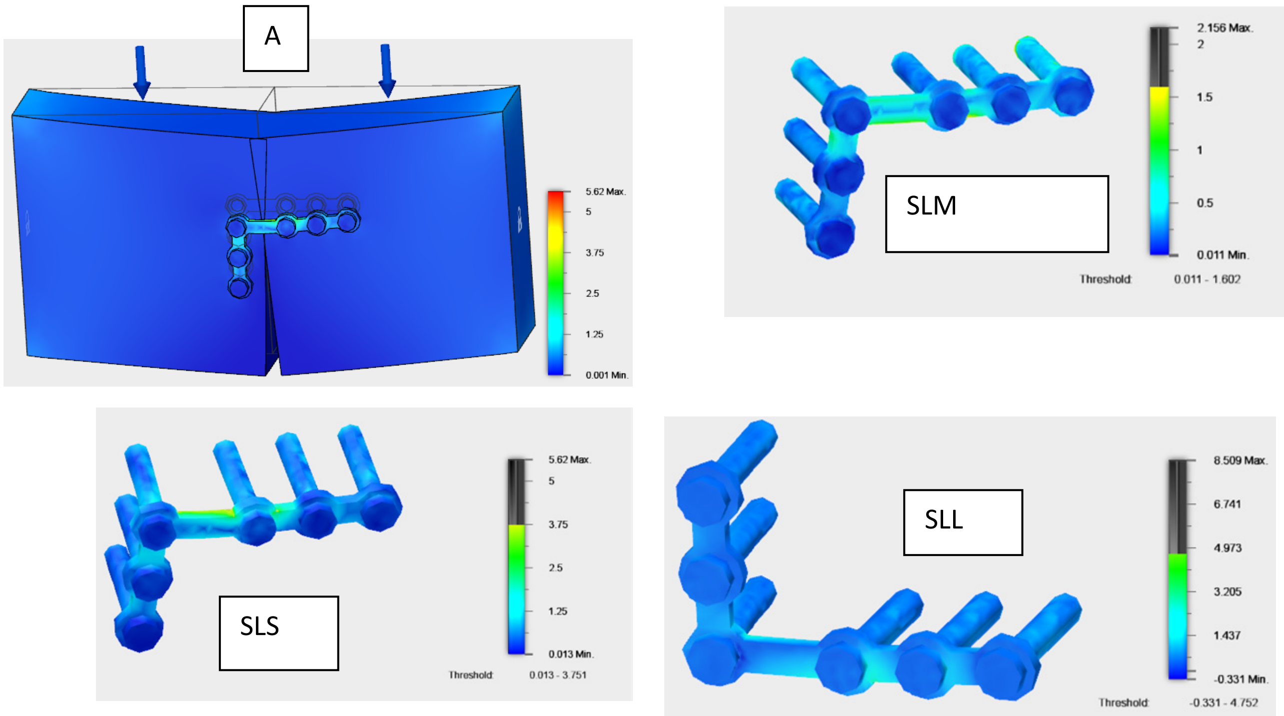
Figure showing displacement on bending through :
Double straight plate and surrounding region
Double straight plate
Double L shaped plate

Fig. 4: Stress on bending through single straight plate



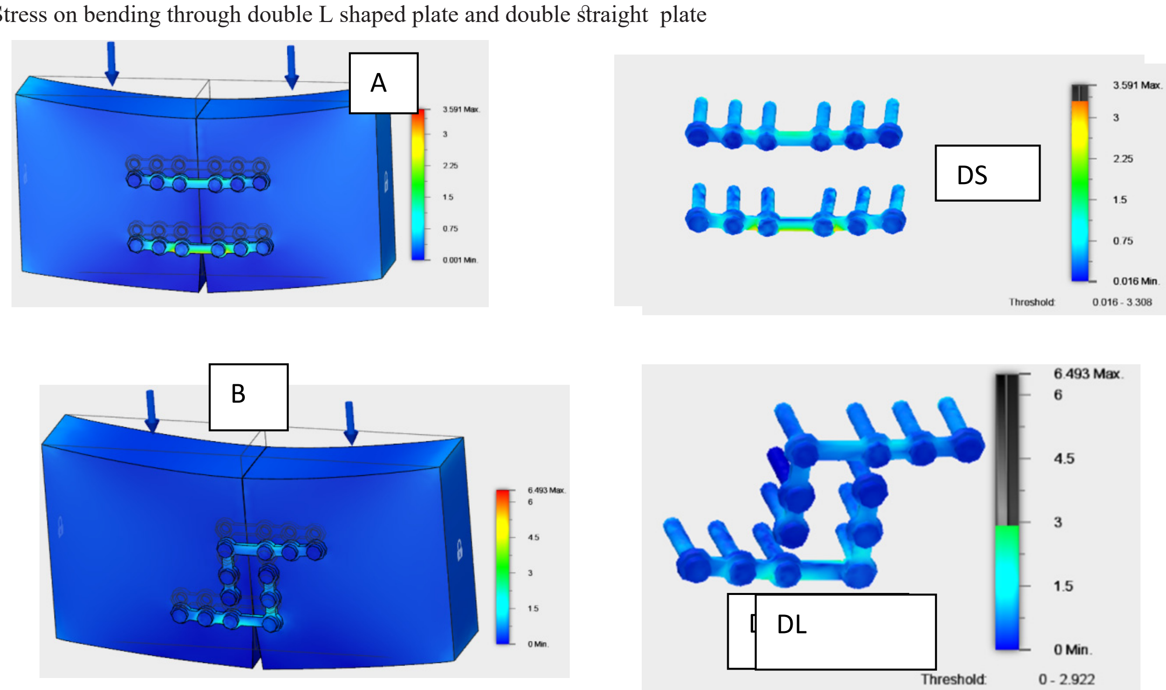
A- Stress distribution through the superior border single straight plate and surrounding region
SSS- Stress distribution through the superior border single straight plate
SSM- Stress distribution through the middle single straight plate

Fig. 5: Stress on bending through single L shaped plate



Stress distribution through
A-single L shaped plate at the superior border and surrounding region
SLS-single L shaped superior border plate
SLM- single L shaped plate at r=the middle
SLL- single L shaped plate at the lower border

Fig. 6: Stress on bending through double L shaped plate and double straight plate



Stress distribution through
A-Double straight plates and surrounding region
B- Double L plate and surrounding region
DS-Double straight plate
DL-Double shaped plate

Table 4: showing stress in mega pascal and displacement in mm through different categories on bending

Variable	SSS	SSm	SSl	SLS	Sl m	SLl	Superior plate of DS	Inferior plate of DS	DS total	Superior plate of DL	inferior plate of DL	DL total
Vonmeses	1.419	1.732	4.287	3.751	1.602	3.688	1.379	3.413	3.309	1.274	3.251	2.922
Displacement	0.002877	0.00283	0.003545	0.003624	0.002823	0.002779	0.002845	0.002758	0.002845	0.002809	0.002743	0.002809

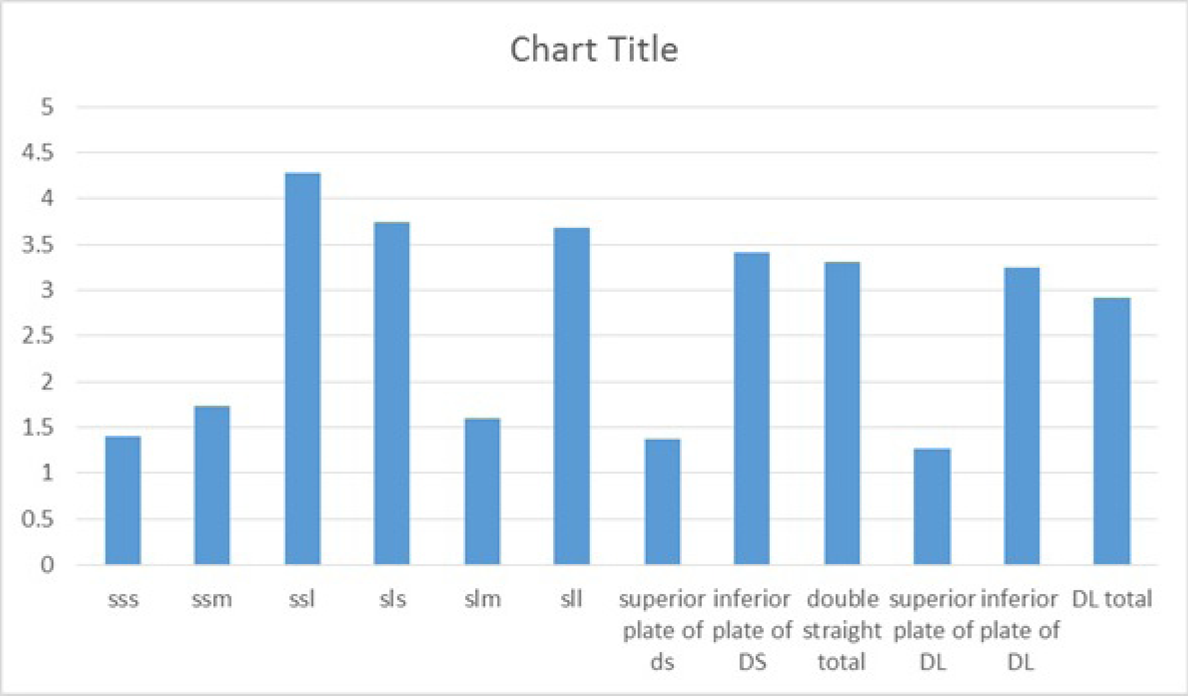


CHART BAR 1 showing stress distribution through different fixation systems
SSS single straight plate at superior border
SSm single straight plate at the middle
SSl single straight plate at the lower border
SL s single L shape plate at the superior border
SLm single l shape plate at the middle
SL l single L shape plate at the lower border
DS double straight
DL double L shape plate

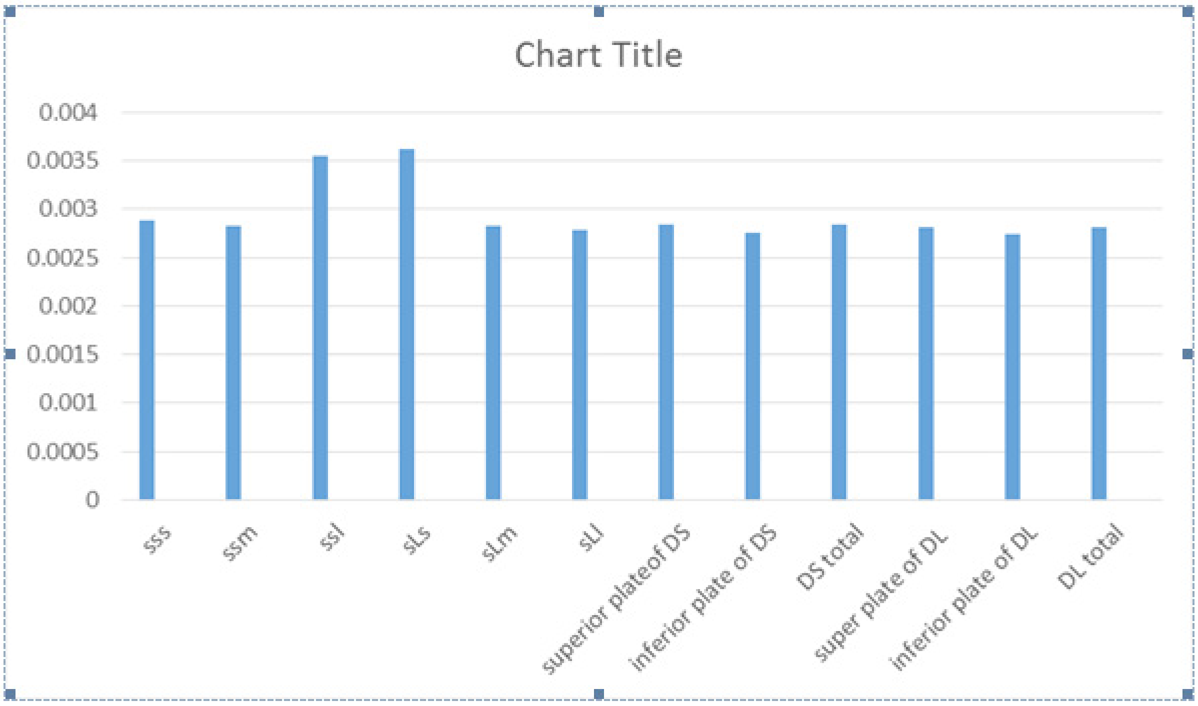
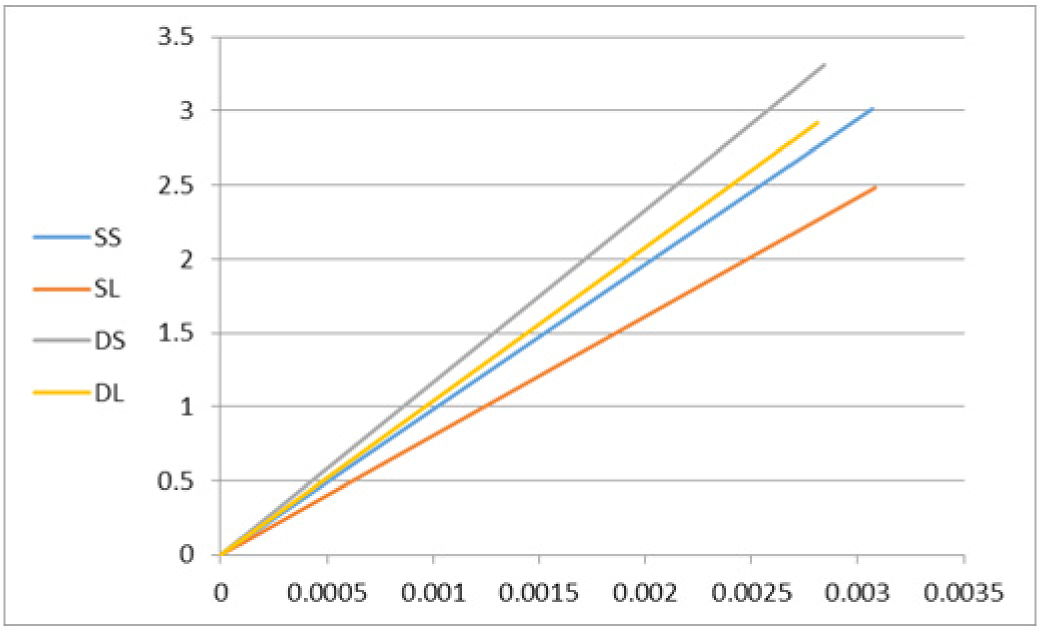


Chart bar 2 showing displacement mm of different systems



Linear graph 1 showing relation between displacement on horizontal axis and stress on vertical axis through different groups on bending
SS-single straight plate SL – single L shaped plate DL – double plate
DL double L shaped plate

As regard torque moment

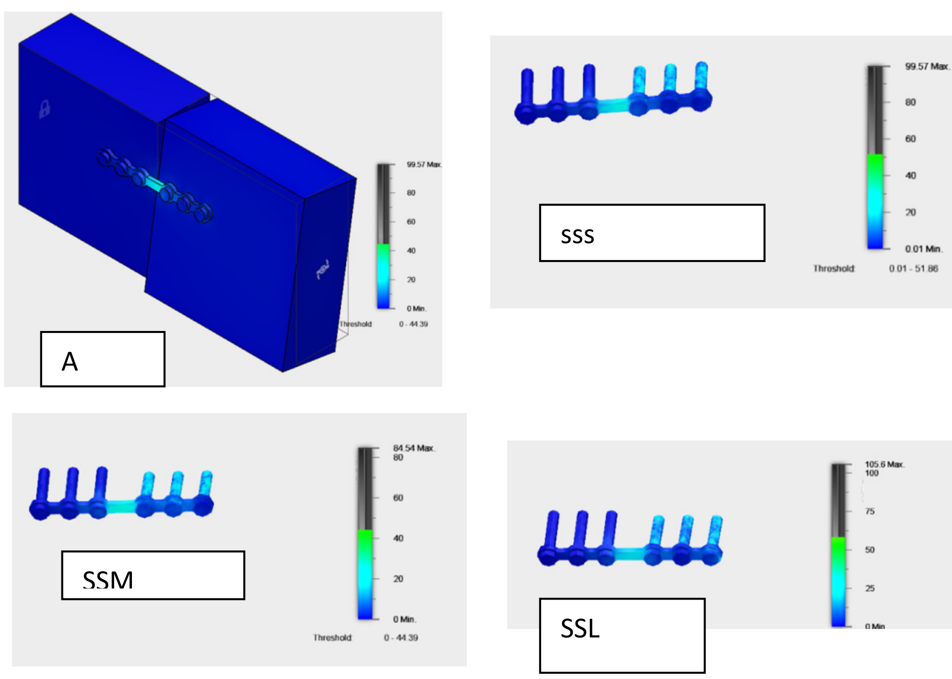
Both torque stress and displacements shown on Figures (7-12) and Table 2 and Chart bar 3 and 4.

As regard single straight plate is highly stressed on inferior border than on superior border and least torque stress resulted on the middle position, the l shaped plate shows less torque stress than straight single plate in all positions ,in the same time double straight plate system is less torque stress than single straight plate and l shaped single plates, while double l shaped plate show the least stress of all systems.

As regards displacement resulted due to torque the single L shaped plate showed less displacement than single straight plate, while double straight plate showed less displacement than single straight and single L shape plate, lastly the double L shape plate showed the least torque displacement and it is to be noted that as the stress increased the displacement also increased in linear relationship, the highest stress is met by highest displacement and the vice versa.

It is to be noted that there is linear relationship between stress and displacement on torque as shown in linear graph 2 which demonistrates that single L shaped plate is more table than single straight shaped plate, also double L shaped plate is more stable than double straight plates.

Fig. 7a: showed stress distribution through single straight plate



Stress distribution on torque through
A-stress distribution through single straight plate and surrounding region
SSS- single straight plate at the superior border
SSS- single straight plate at the middle
SSL- single straight plate at the lower border

Fig. 8: stress distribution through the single L plate

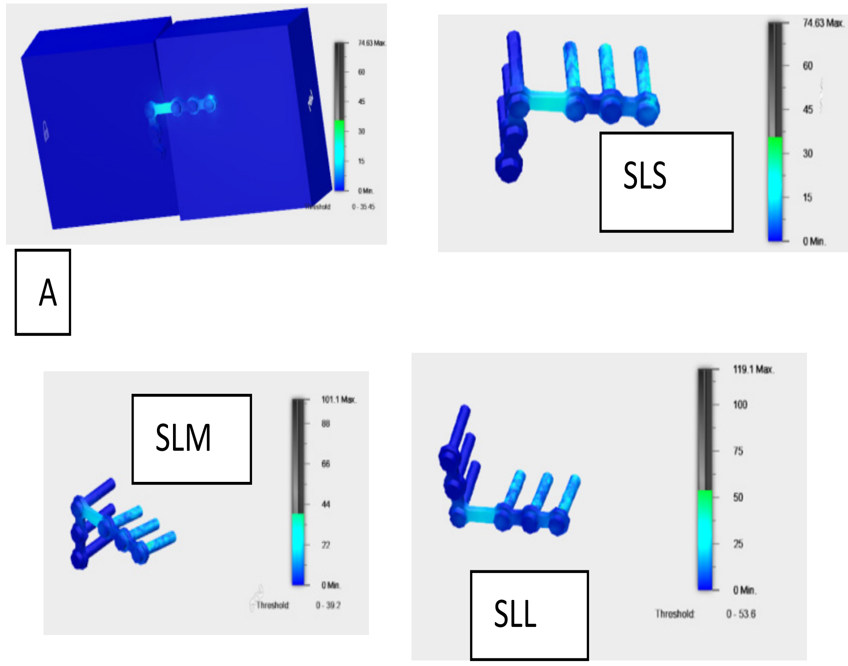


Figure showing stress distribution through L shaped plate
SLS – single L shaped plate at superior border
SLM- single l shaped plate at the middle
single l shaped plate at the middleSSL

Fig. 9 a: showed stress distribution through double straight and double L plate

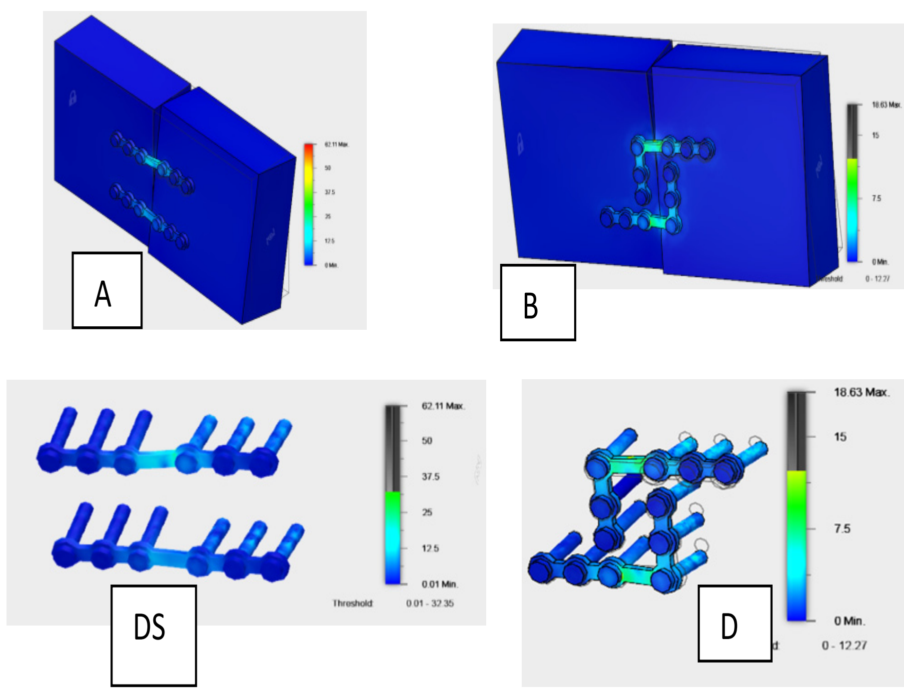


Figure showing stress distribution on torque through:
A-double straight plate and surrounding region
B- Double L shaped plate and surrounding region
DS- double straight plate
DL- double L shaped plate

Fig. 10: displacement through single straight plate

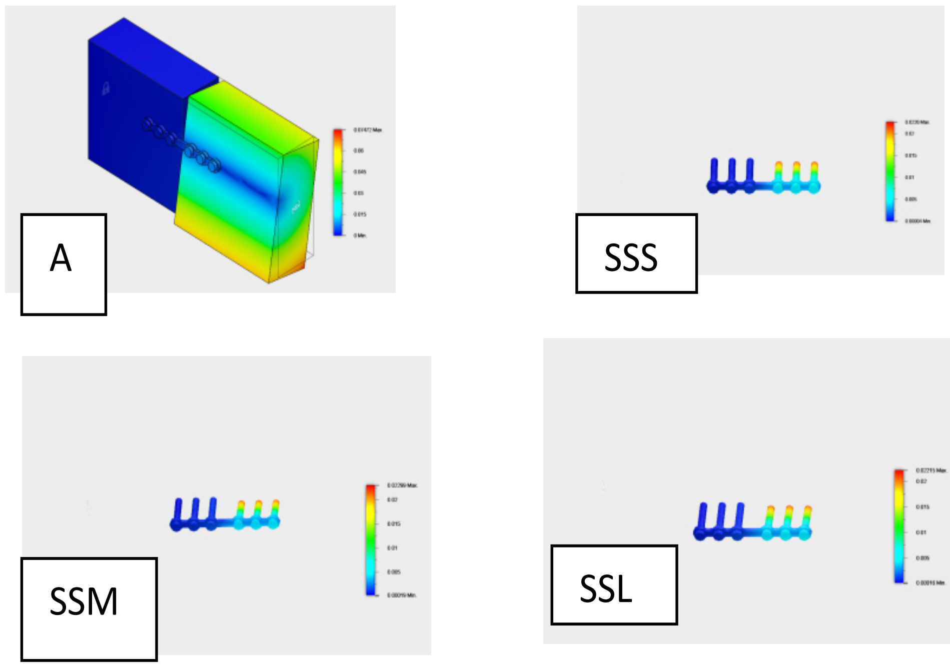


Figure showing displacement on torque through
A-single straight plate superior border and surrounding region
SSS-single straight plate at superior border
SSM-single straight plate at the middle
SSL-single straight plate at the lower border

Fig. 11: displacement through single L plate

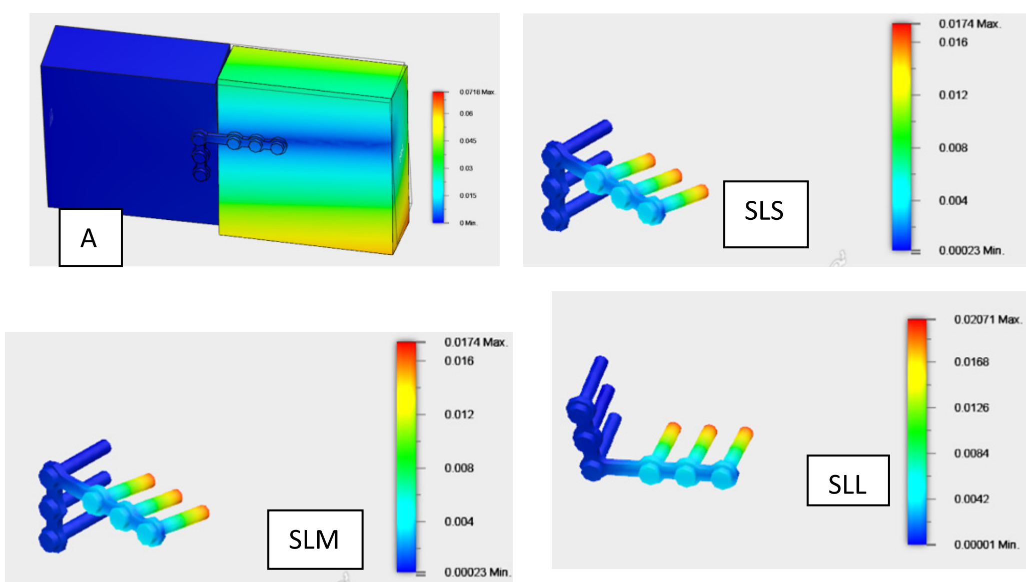


Figure showing displacement on torque through
A-single L shaped plate at the superior border and surrounding region
SSS-single straight plate at the superior border
SSM-single straight at the middle
SSL- single straight plate at the lower border

Fig.12: displacement through double straight and L shaped plate

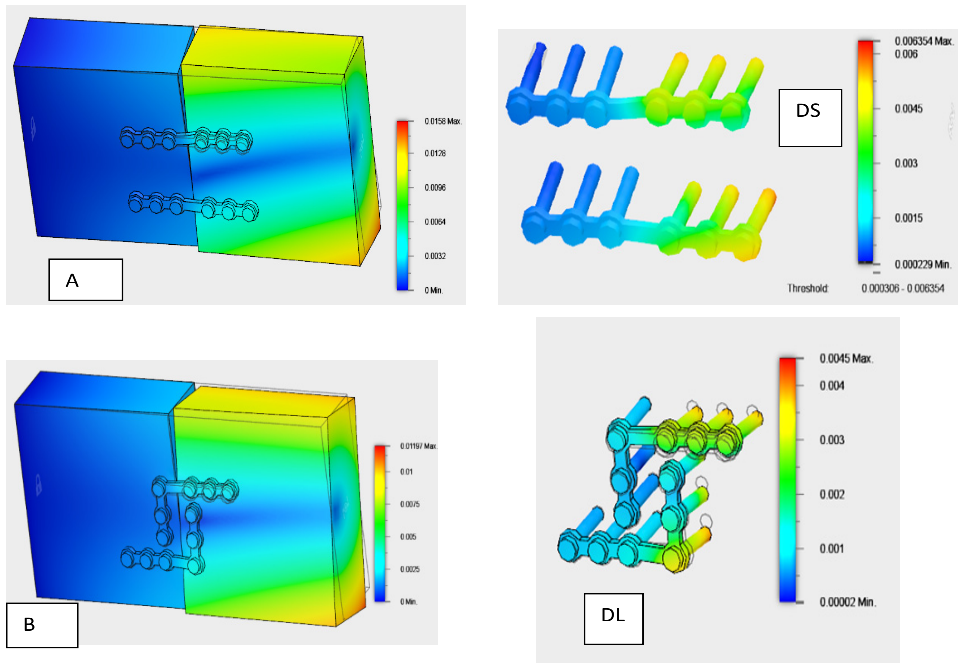


Figure showing displacement through:
A- Double straight plates and surrounding region
B- Double L shaped plate and surrounding region
DS-double straight plates
DL –double L shaped plate

Table 5: showing stress in mega pascal and displacement in mm through different categories on torque

Variable	SSs	SSm	SSl	SLs	SLm	SLl	Superior plate of DS	Inferior plate of DS	DS total	Superior plate of DL	inferior plate of DL	Double L total
Vonmeses	51.86	44.39	58.5	35.45	39.2	53.6	32.36	10.95	37.35	25.81	10.02	26.555
Displacement	0.0226	0.02299	0.02215	0.02065	0,0174	.02071	0.005579	0.006354	0.006354	0.005955	0.004594	0.005955

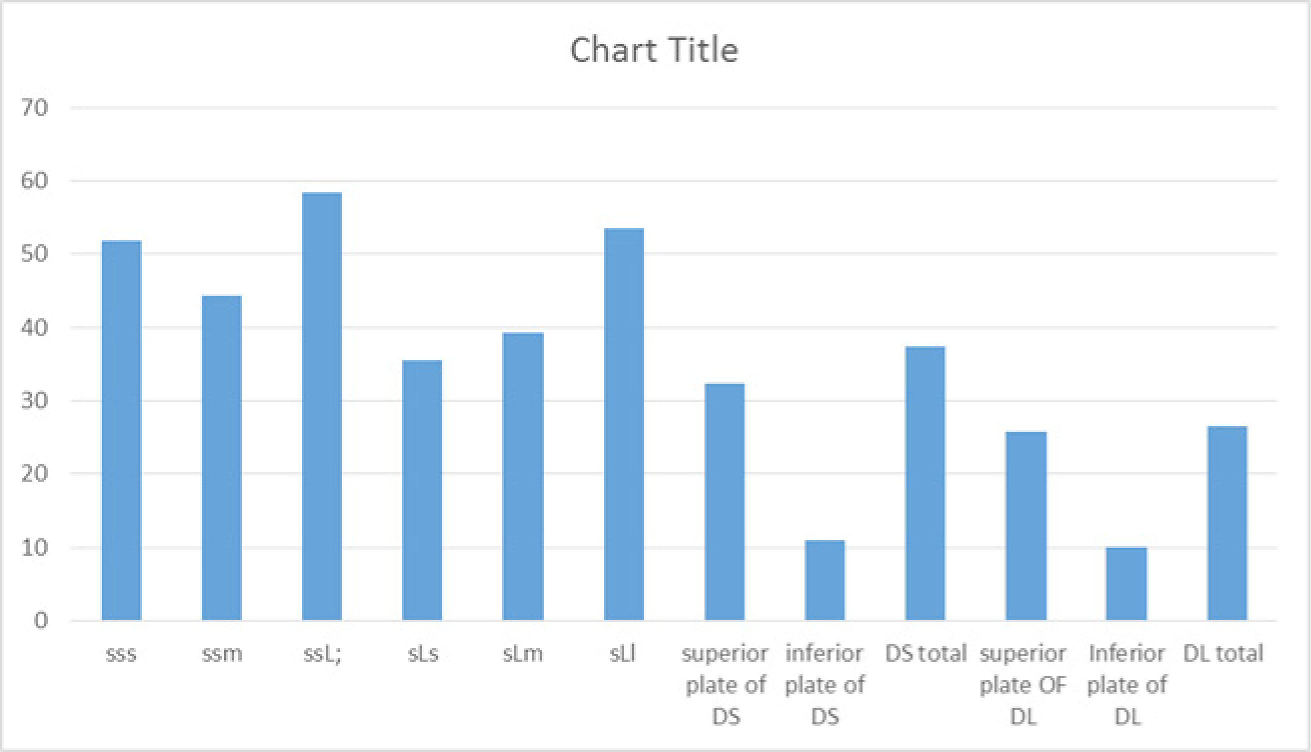


Chart bar 3 showing stress distribution through the different systems on torque

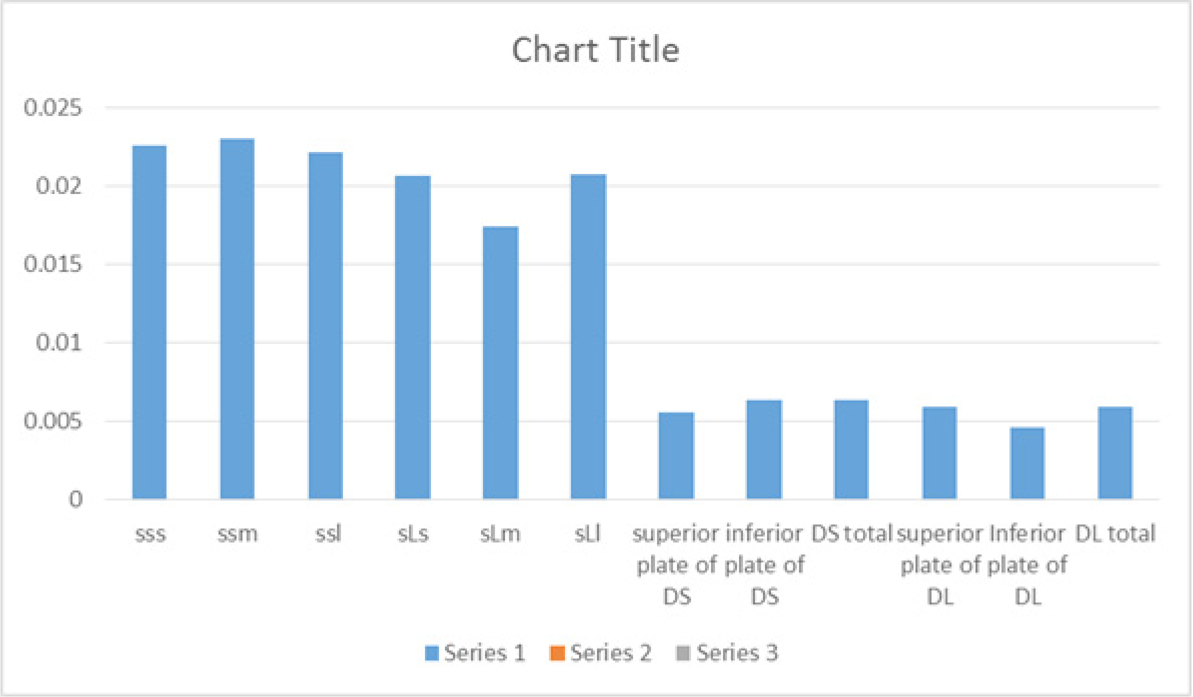
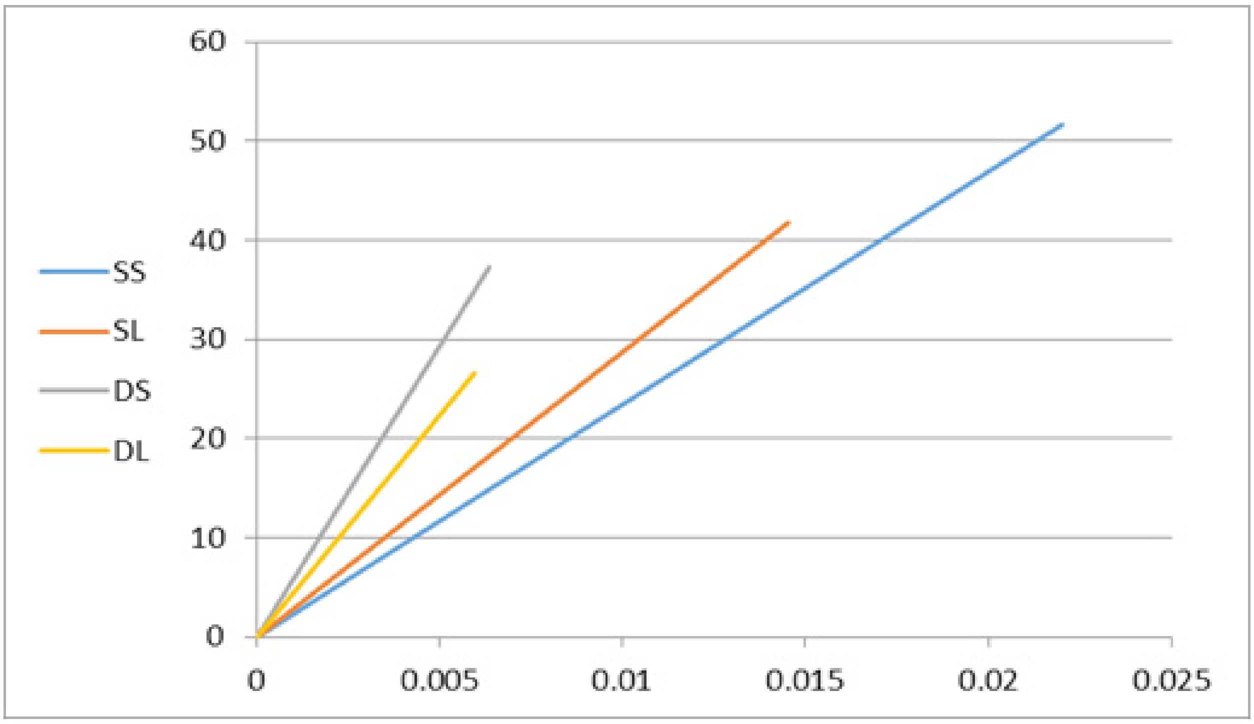


Chart bar 4 showing displacement through different system on torque



Linear graph 1 showing relation between displacement on horizontal axis and stress on vertical axis through different groups on torque
SS-single straight plate SL – single L shaped plate DL – double plate
DL double L shaped plate

DISCUSSION

Finite element analysis is a computational numerical new technology used to simulate any structure ,which is divided into finite elements through a process called meshing , then the material properties of this structure are recorded by this method, then the structure subjected virtually to different forces and controlled by certain boundary conditions , the resulted stresses , strains and displacements are calculated through this methods[9].

Finite element analysis used for multiple maxillofacial applications as trauma, orthognathic surgery, prosthodontics and orthodontic work.[10]

Multiple researches have studied the biomechanical behavior of the mandible that is fractured at the angle and condylar process after reduction and fixation with miniplate using finite element analysis however the symphyseal fracture has not explored sufficiently.[11,12]

Through this study, the fractured segment of the mandible was represented with two separated blocks having the same dimensions of the mandibular symphysis as regards the height, the width and thickness according to the study of Alkhateeb *et al.*[6].

All the materials used through this study were considered homogenous ,isotropic and linearly elastic in contrary to the facts that the mandibular bone is anisotropic and viscoelastic, these acts done to facilitate the study , and multiple studies used these considerations for the same purposes[7,13].

According to Tam study[2], on application of bite forces on the occlusal plane, the symphyseal region reveals negative bending moment where there is compression at the upper border and tension at the lower border, while on molar loading there is torque moment.

While the normal bite force ranges from 600 to 800 newton according to the study of Hsu *et al.*[14], the selected bite force for this study was 100 newton this is because of reduction of the bite force on traumatized mandible due to pain, edema and mutilation of the traumatized tissue according to the study of Kshirsagar *et al.*[15] were the bite force may be reduced to 3-27 kg or (29- 264 N) and application of 100 N through biomechanical study also stated through the study of Haug *et al.*[16]

Through this study, on application of bite force at occlusal plane on both side of the fracture, the model showed negative bending moment and this is the same that occurs at symphysis region according to the study of Tam *et al.*[2]

As regards single plates either straight or L shaped plate, it is obvious that the plate position affect stress distribution, the inferior border positioned plate is highly stressed than middle and superior border positioned plate, this is because the high tension resulted at the lower border due to negative bending, the L shaped plate is less stressed and less displaced than single straight plate ; and this may be due to the three dimensional design which leads to more stability than linear plate, as the single plate positioned more inferior the fracture gap decreased gradually, but the plate become highly stressed and deformed, and this can be managed by increasing the thickness of the plate or addition of another plate at the superior border these finding is in accordance to the study of Arbag *et al.*[17]

Through this study, L shaped plate that is located at the middle show little displacement than that is located at the inferior border or the superior border.

As regards the double straight plates system, it showed less stress and displacement than the single straight and L shaped plate, this may be due to the superior border plate absorbs more applied load and resist deformity so that the load reached the lower border plate is minimized so that the lower border late in double straight system showed less stress and displacement than single straight and L shaped plate and this is in accordance to the study of Wang *et al.* [7] and the study of Arbag *et al*.[17]

While double L shaped plate showed less stress and displacement than double straight plate system and this may be due to the additional support provided by double L shaped plate that form rectangular construct surrounding the fracture line and more stability at three dimensions.

As regards torque moment, this research provides obvious torque loading where there is type of loading called moment load provided by FUSION software, and this clear torque loading is not provided through many researches that studied the mandibular behavior on treatment of the symphyseal fracture[18,19].

As regards torque moment, the single L shaped plate show less stress and torque displacement than single straight plate, the torque stress on both single systems showed higher value at the lower border than the superior border, the least displacement value was recorded when the L shaped single plate placed at the middle as regards the double straight plate system it showed less stress and displacement than single plate systems either straight or L shaped plate. Also, the double L shaped plate showed less torque displacement and stress than double straight system.

In our study, high convergence was used for the results as regards the von Mises stresses and total displacement to obtain accurate solution and this is done by using finer elements in sequential steps till the solutions become stable and this done according to the study of Ayali *et al.*[18]

Through this study, acrylic material was used for mechanical testing because it is similar to mandibular bone, and used for this purpose in literature[20,21].

CONCLUSION AND RECOMMENDATION

From the mentioned discussion, the following can be concluded :

1- Double plates can provide more stability for healing of the fracture.
2- L shaped plate design gives more stability than straight plate of the length and dimension.
3- Changing the position of the single plate affect the stability of the fracture, middle positioning of the single plate may give more stability than other positions.
4- Finite element methods is valuable conservative technology can be used for designing of the fixation systems and selection the optimum positioning for their application.

CONFLICT OF INTEREST

There are no conflicts of interests.

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