Effect of Screws Placement on Locking Compression Plate for Fixating Medial Transverse Fracture of Tibia

Ehsan Taheri*1, Behrooz Sepehri2, Reza Ganji3, Cyrus Nasirai4

1Mashhad Branch, Islamic Azad University, Mashhad, Iran

2Department of Mechanics, Mashhad Branch, Islamic Azad University, Mashhad, Iran

3Department of Orthopedic Surgery, North Khorasan University of Medical Sciences, Bojnurd, Iran

4Department of Civil Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran

*1ehsan_t683@yahoo.com; 2b_sepehr@mshdiau.ac.ir; 3armin.ganji@gmail.com; 4c.nasirai@gmail.com

***Abstract*- Locking Compression Plates (LCP) are useful fixation devices for tibia and other human long bones. Orthopedists use LCPs with various numbers of holes to fix bone fractures [1]. Not all of holes on plates are often used with Screws so various screw positioning is possible in operations. In this research, a 3D model of tibia is created with the exact geometry of the real bone by using CT scan images of the human right leg .It was materialized by MIMIX and developed in ABAQUS software. This was done considering whole bone material including bone marrow and cancellous bone that have been mostly ignored in previous researches [2]. The model is mechanically validated and verified in comparison with response and behavior of previous cadaveric bone studies [3].**

Comparing the stress and stiffness in various positioning of screws on a stainless steel 11 holes LCP used for fixating tibia with a medial transverse fracture in various treatments and finding the optimized screw omission, was the purpose of this paper which can help orthopedists to choose the suitable cases of screws positioning of fixation devices.

Keywords*- *Locking Compression Plate; LCP ; Screw Placement; Transverse Fracture ; Finite Element Analysis (Fea); Stress Analysis

I. INTRODUCTION

In skeleton bones fractures, Tibia bone has most statistics [4]. Many types of fixation devices in various sizes and dimensions including internal and external devices have been designed for fixating this bone [5]. Medial fractures due to diametrical pressing, strikes, torsion etc. are common for this bone especially in car accidents. Locking Compression Plates (LCPs) nowadays are very practical solution for this type of tibia and other long bone fractures.

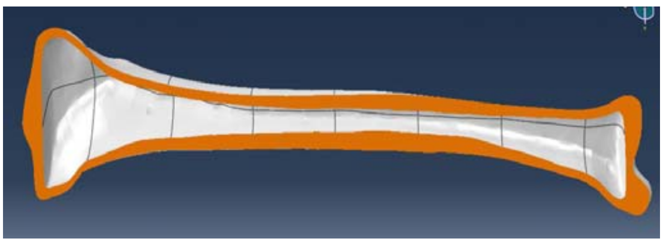
The fixation devices and the surgical techniques for internal fixation have evolved since 1960s to provide better and improved bone healing [6]. Various injury mechanisms can be seen to be used in long bones, which bending and torsional moments have been considered as major affecting factors [7].

Many types of compression plates as Locking Compression Plates (LCPs) have been manufactured. The recent manufactured LCPs have been designed with the combination holes which can house the locking screws and the conventional screws [8]. Using fixation plates and the optimum number of screws and their placement depends on many factors and still is a discussion within orthopedic surgeons [9-10]. This study will explain the optimum omission and placement of screws choosing for a particular type of tibial fracture through computational finite element method. Results in terms of stress distribution and stiffness can be utilized for the advancement of fracture management and development of optimized screw omission on fixation locking compression plate.

II. METHOD

A. 3D Tibia Bone Model Designing

First, it was needed to have a perfect verifiable model of tibia bone in order to have trustable results in performing the mechanical computational experiences. So a perfect right leg tibia bone with the length of 375 mm was modeled. This was done using computer tomography (CT scan) of a 32 years old man with no skeleton problem and was edited in Mimics 10.01. Results were exported to Solid works 2012 and after performing the required levels imported to Abaqus 6.11-1. The model was a composite simulated as a real tibia considering cortical and trabecular bone (Fig. 1). Fixation device that was used in this study was a stainless steel LCP and its Locking Screws that was modeled as a commercial 11 holes LCP (Fig. 1).



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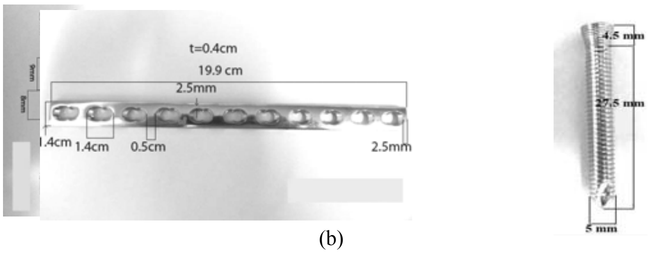


(b)

Fig. 1 Axial section of the model Tibia bone model in Abaqus that shows the trabecular bone (inner mass) and cortical bone (outer shield) (a) Commercial 11 holes LCP used in transverse fracture of tibia and its locking screw (b)

B. Whole Bone Model Validation

Before beginning experiences on the bone and fixture, it was necessary to verify that response of model to mechanical loadings in comparing with a real bone results. Abaqus perfectly recognized and separated two parts of imported bone model: the cortical bone and the cancellous bone including bone marrow. Spongy bone of the epiphysis parts of the tibia were modeled too. Bone marrow and spongy bone both have softness in material and low strength against mechanical loading, also their density are close so were merged together initially in the Mimics software.

Two main parts i.e. trabecular mass that is inner and cortical shield that is the outer part were assembled. Thus the complete model was ready to perform tests and simulations. Materials of different parts had to be defined and the parts were meshed.

Anisotropic material of human long bone were defined for the model from another study [11] (Table I), and meshing was done with 67496 hexahedral elements for cortical and 31371 tetrahedral elements for trabecular bone part of the model.

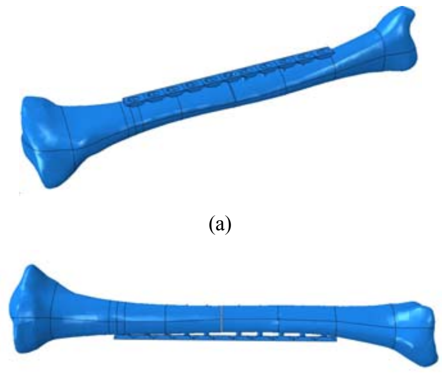
Axial torsion and four points bending of obtained 3D model of tibia were applied in Abaqus same as test conditions of Luca Cristofolini and Marco Viceconti study on cadaveric and composite tibia bones [3]. Thus four points bending with load of 500 N and actuator speed of 0.05 mm/s were applied so that loading was interrupted when deflection of 0.5 mm was reached. The torque was applied with actuator speed of 0.23 mm/s so that the knee was twisted towards intra-rotation until rotation of 5° was reached. Then bending and torsion stiffness of 3D model was calculated to compare with the results of real cadaveric bone stiffness.

TABLE I MATERIAL PROPERTIES USED IN 3D MODEL OF BONE [11]

Material Properties	Cortical Bone	Trabecular Bone
Young's Modulus (MPa)	E_x=18.400 (longitudinal)	E=1.061
	E_y=7.000 (transverse)	
	E_z=8.500 (radial)	
Poisson's Ratio	ν_{xy} =0.12	ν=0.225
	ν_{yz} =0.37	
	ν_{xz} =0.14	

C. Assemble And mechanical Analysis

Transverse fracture was simulated at the middle of tibial shaft and separated with a 1mm gap [12]. Locking Compression stainless steel with Young's modules of 210GPa and Poison ratio of 0.3 [12] on a plate with 11 combination holes was modeled ,assembled and positioned at the medial side of tibia model where the bone is not in tension[13] so that the middle hole was positioned right on the gap (Fig. 2). The threads on locking screws and thread holes were ignored; however, their effects of providing strong fixation were simulated. All contacting surfaces were assigned with a friction coefficient of 0.3 [14].



(a)

(b)

Fig. 2 Assembled 11 holes LCP on tibia 3D model in Isometric (a) and medial lateral (b) view with ten locking screws

Bending in planes of anterior-posterior and medial-lateral and torsion for 8 styles of treatments of screws locations was applied in styles of Korvick DL and Monville JD study on bovine tibia (Table II) [15] and spectrums of Von Mises stress distribution were obtained.

TABLE II SCREWS OMISSION STYLES ON THE PLATE HOLES [15]

Treatment	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Control	L[a]	L	L	L	L	_	L	L	L	L	L
1	L	L		L		_		L		L	L
2	L		L		L	_	L		L		L
3			L	L	L	_	L	L	L		
4	L	L	L			_			L	L	L
5	L			L	L	_	L	L			L
6		L		L	L	_	L	L		L	
7	L	L			L	_	L			L	L
8		L	L	L		_		L	L	L	

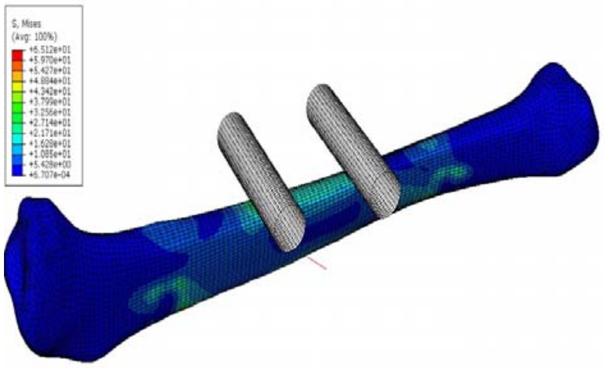
a. "L" Shows a LCP hole which house a locking screw.

III. RESULTS

A. *whole Bone 3D Model Stress and Stiffness*

Stress spectrums were obtained from four points bending and torsion loading on the 3D model (Fig. 3). So bending stiffness in two anterior-posterior and lateral-medial planes were calculated respectively 3031.78 N/mm and 1725.41N/mm. Also torsion stiffness was obtained 5759.37 N.mm/degree.

For verification the mechanical responses of the model the obtained stiffness compared with a good cadaveric right tibia bone results of Luca Cristofolini and Marco Viceconti study [3] (Fig. 4).



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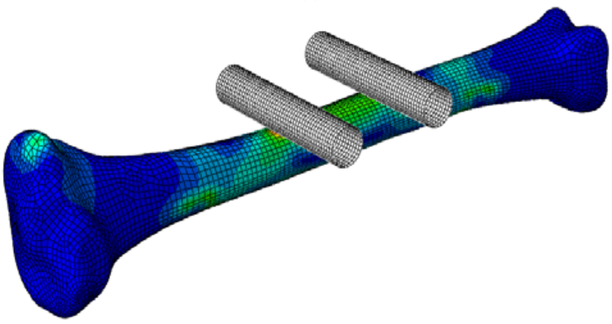

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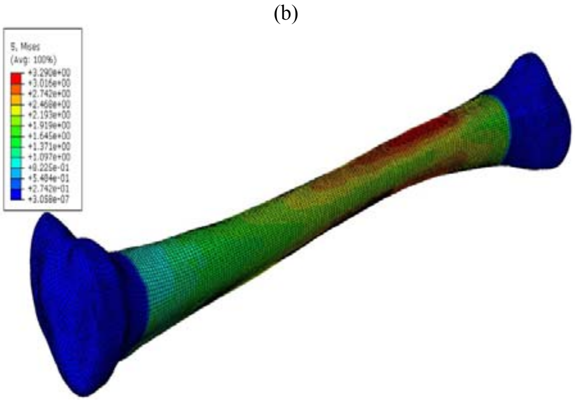

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Fig. 3 Von Mises stress spectrum in Lateral-medial (a) and anterior-posterior (b) planes of four point bending and 5° Torsion (c)

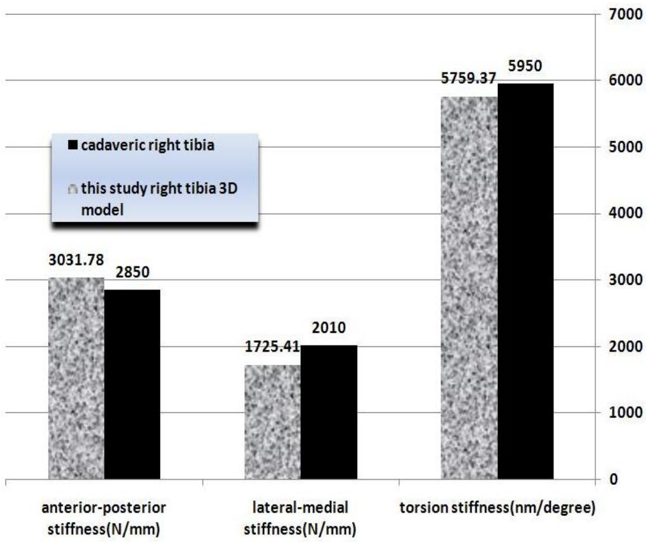
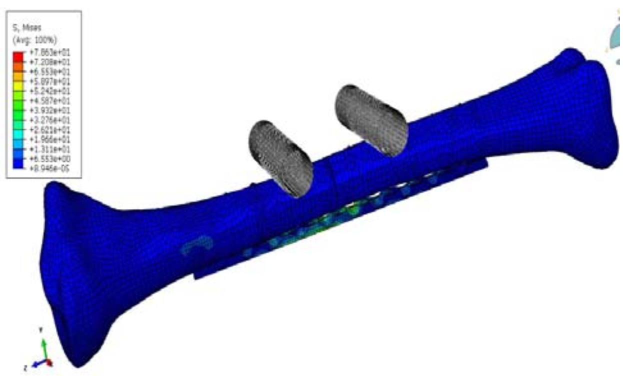


Fig. 4 Histogram representation of comparing the obtained stiffness of this study whole tibia finite element model with cadaveric one from Luca Cristofolini and Marco Viceconti study [3]

B. *Fixated Tibia Stress And Stiffness*

The spectrums of Von Misses stress distribution of four points bending (Fig. 5 and Fig. 6) and spectrum of torsion stress distribution (Fig. 7) of the fixated tibia in a control treatment and 8 other treatments (Table II) were obtained. Their stiffness was calculated and has been compared together and with the whole bone model results for considering and finding the optimized biomechanical treatment (Fig. 8).



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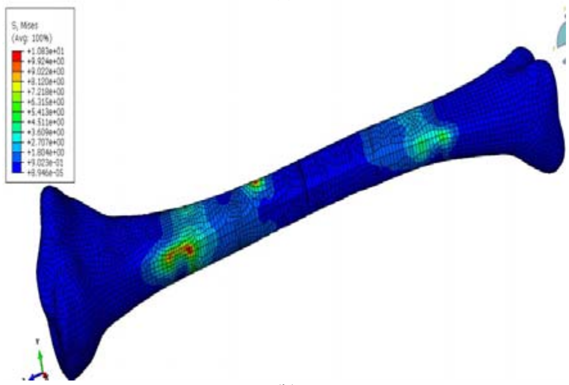

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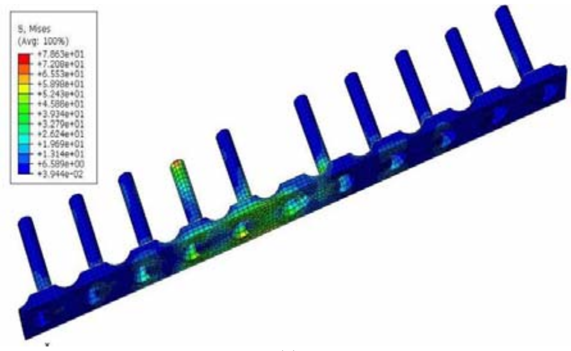

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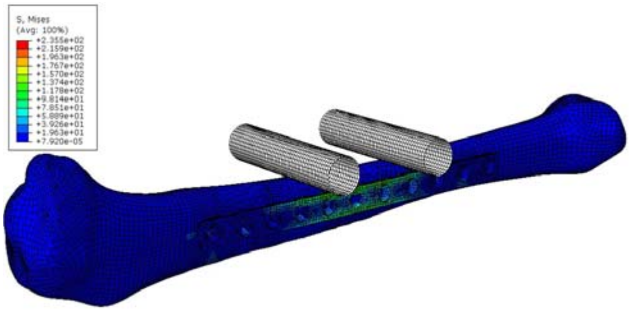
Fig. 5 Stress distribution in four points bending for anterior-posterior direction of tibia fixated with 11 holes LCP in control treatment. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.



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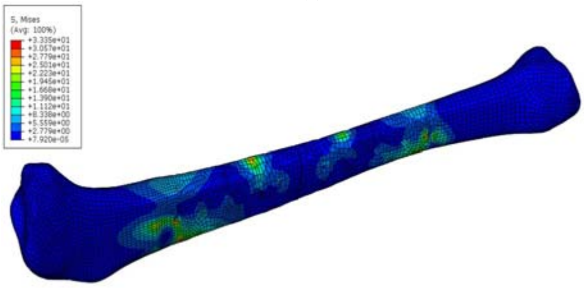

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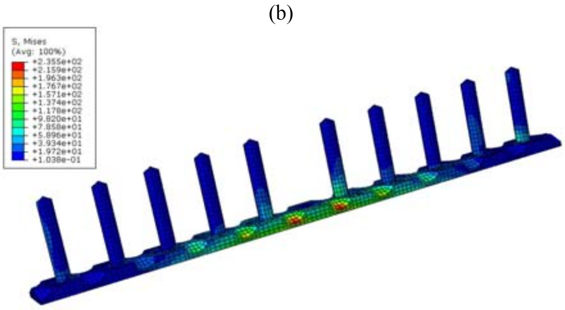

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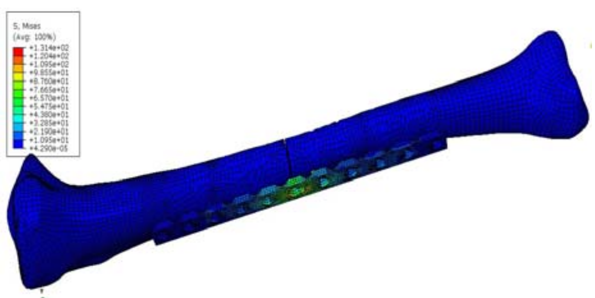
Fig. 6 Stress distribution in four points bending for medial-lateral direction of tibia fixated with 11 holes LCP in control treatment. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.



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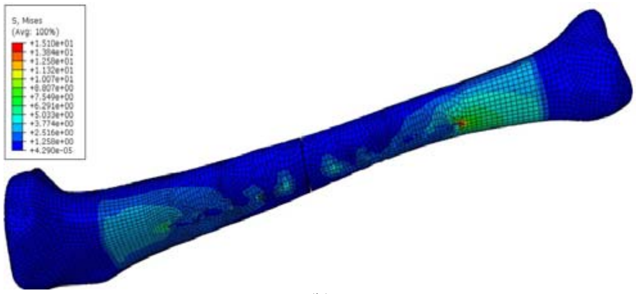

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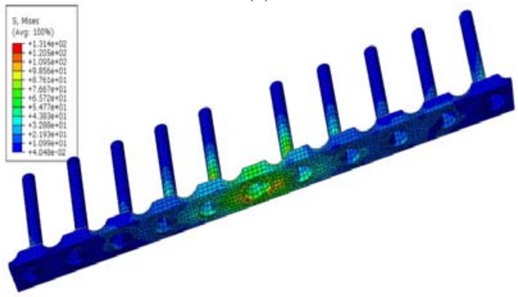

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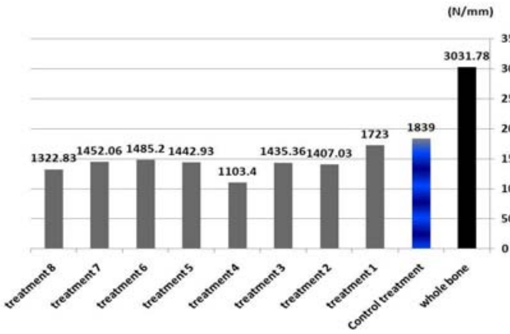
Fig. 7 Stress distribution in 5° torsion of tibia fixated with 11 holes LCP in control treatment. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.



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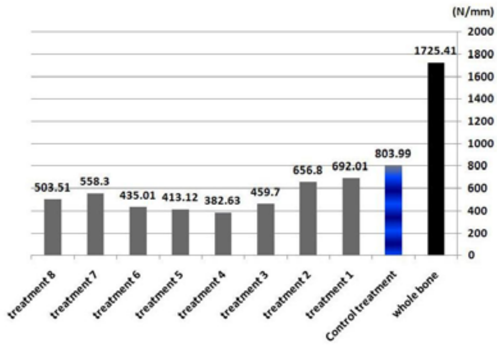

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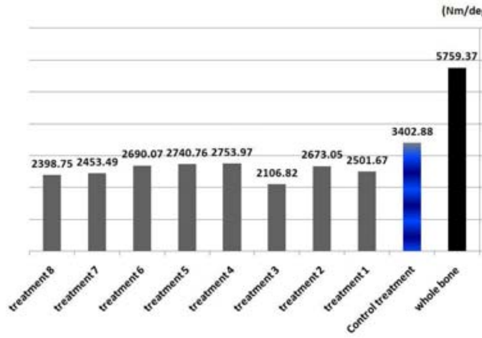

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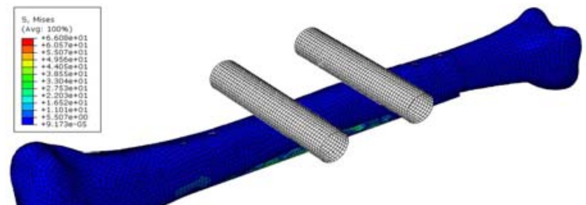
Fig. 8 Histogram representation of anterior-posterior (a) and medial-lateral (b) direction bending stiffness and torsion stiffness(c) in whole bone and fixated tibia in various treatments of screw omission on LCP.

IV. DISCUSSION

The finite element bone model used in this study was obtained from whole bone material modeling without ignoring lower strength material of spongy bone and marrow. As regards the model was verified by stiffness comparison with the cadaveric one experienced by Luca Cristofolini and Marco Viceconti [3], so the results of this analysis with 7.82% of average of errors can be reliable.

The objective of this study is to analyze stability of fixated tibia just after surgical operation when the callus gap is empty and finding the best screws omission treatment using locking compression plate with locking screws to help orthopedists to choose suitable treatment in fixating human tibia medial transverse fractures. Considering stress spectrums in bending and torsion, it was concluded that control treatment made stresses to concentrate significantly in proximal and distal region of tibia and middle of LCP. Comparison of maximum Von Misses stress on LCP, screws and bone, showed that Treatment 1 had minimum stress concentration (Fig. 9) and control treatment had maximum one. So control treatment totally can be rejected for using in practice of operations. Bending stiffness histogram (Fig. 8) showed that Treatment 4 had minimum bending stiffness in comparison. So stability of this style of screw positioning may not to be trustable and especially may not be suitable for fat patients operation. Fig.8-c showed that Treatment 3 has minimum torsional stiffness and Treatment 4 has the maximum one. Considering bending histograms of Fig.8 showed that Treatment 1 had greatest bending stiffness in both lateral-medial and anterior-posterior direction and torsion stiffness of this style was 2501.67 Nm/degree that was close to the average stiffness of treatments (2539Nm/degree) so totally its stiffness can be acceptable. Stress distribution of this model was closer to whole bone than other ones (Fig. 9, Fig. 10 and Fig. 11).



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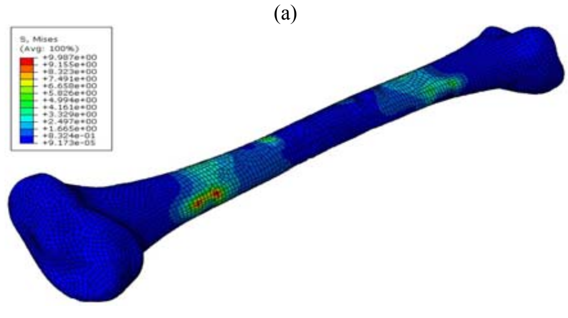

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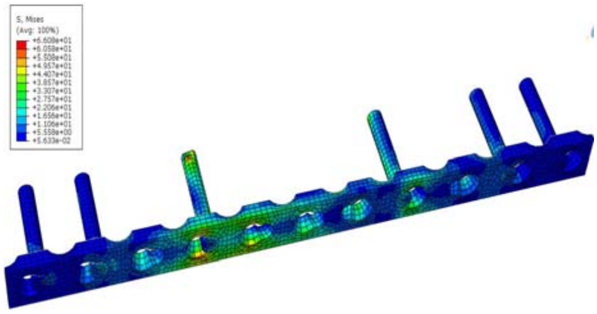

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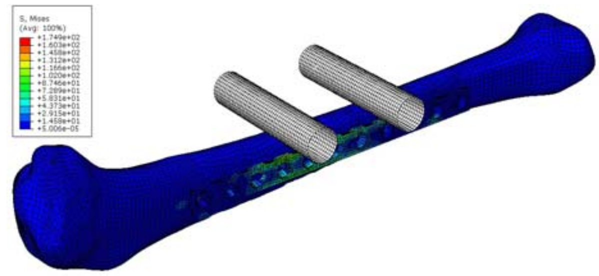
Fig. 9 Stress distribution in four points bending for anterior-posterior direction of tibia fixated with 11 holes LCP in treatment 1. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.



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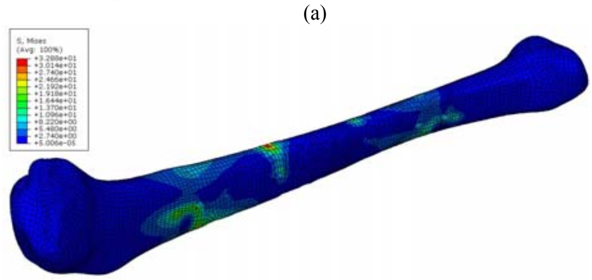

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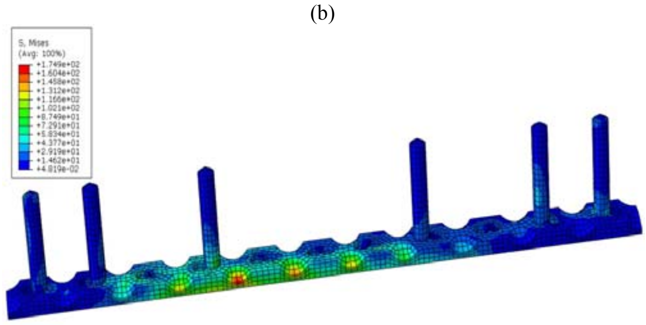

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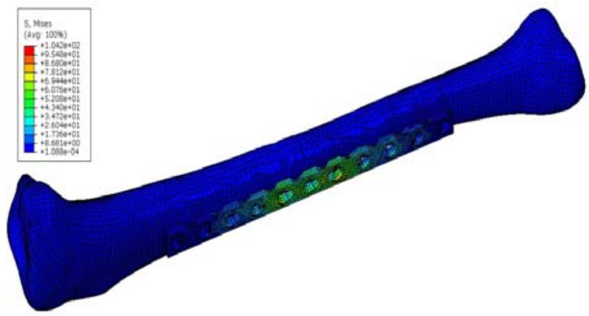
Fig. 10 Stress distribution in four points bending for medial-lateral direction of tibia fixated with 11 holes LCP in treatment 1. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.



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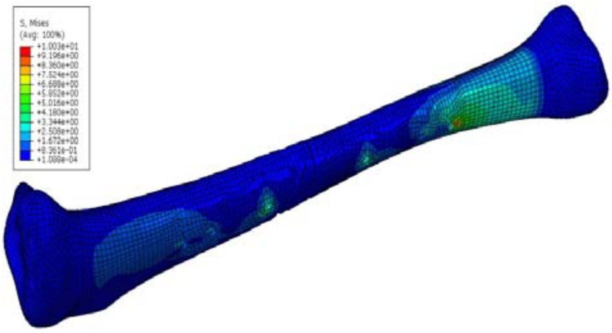

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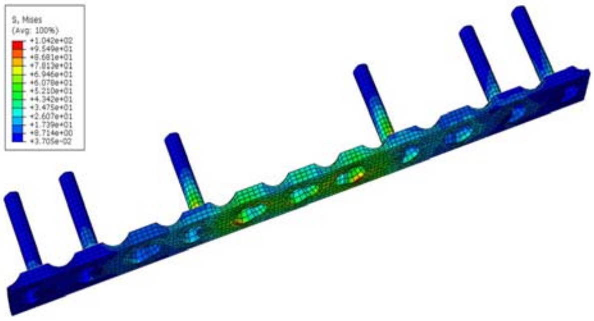

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Fig. 11 Stress distribution in 5° torsion of tibia fixated with 11 holes LCP in treatment 1. All part assembled (a), Tibia bone (b) and LCP and screws(c) stress spectrums.

Maximum of Von Misses stresses created in fixated bone and fixture elements of Treatment 1 in medial-lateral, anterior-posterior plane of bending and torsion was respectively 174.9 MPa, 66.08 MPa and 104.20 MPa while this results were 235.5 MPa, 78.63 MPa and 131.4 MPa for control treatment. This indicated that Treatment 1 reduced about 23% of average stresses on fixated tibia in comparison with control treatment that it was salient value.

V. CONCLUSION

Based on analytical results significant deference between mechanical behaviors of the various screws positioning on the LCP was observed. Two major items in using fixation devices should be considered. First one is stability of fixated bone and second is stress distribution. Low stability treatments may get to failure in short time after surgical operations or as bone bear a force more than its strength .Sometimes not to attention to second item cause stress shielding and screws loosening that are major problems and risks for bone fracture fixation. Although stiffness results show that style of control treatment screw positioning has maximum stiffness in comparison with other treatments but stress concentration and maximum stress is important item that can lead the fixated bone to failure cause of stress shielding or screw loosening [16]. The current research showed that Treatment 1 of screw omission that hole numbers 1, 2, 4, 8, 10 and 11 are positioned with screws on LCP had the best biomechanical response to bending and torsion and could be introduced as the chosen fixation treatment of this study for using in orthopedic surgical operations of usual medial transverse fracture of tibia.

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