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Mechanical evaluation for the finite element analysis of intramedullary nailing and plate screw system used in humerus transverse fractures

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ABSTRACT

Aim: This study aims to examine the commonly used plate screw system and intramedullary nailing method in osteosynthesis in humeral shaft fractures in terms of stress shielding using finite element analysis.
Material and methods: Images were obtained by computerized tomography (CT) to create a 3D model of the humerus bone. After the CT images were transferred to the ANSYS 2021 R2 program (ANSYS, Inc., Canons-burg, PA), a transverse fracture model was created from the shaft region of the humeral bone meshed to the humerus bone and modeled in the 3D environment.
Results: The tetrahedron mesh structure was used for the finite element models in our study. The element size was chosen as 3.5 mm for the bone model and 2 mm for the plate and intramedullary nail models. The node numbers of bone, intramedullary nail, and plate were 91230, 462578, and 581352, respectively. The element numbers of bone, intramedullary nail, and plate were 61350, 311285, and 370350, respectively. Maximum stress values of 260 MPa on the nail and 280 MPa on the plate were detected in this study.
Conclusion: Fewer stress values were obtained and stress concentrations were not formed on the implant in osteosynthesis performed by intramedullary nailing. It can be concluded that this study may guide further studies for those focusing on it and may contribute to the development of a more comprehensive understanding of the topic.

1. Introduction

Humerus fractures are commonly detected among adults. It was reported that humerus fractures occur in 5–8% of adult extremity fractures. Humerus shaft fracture consists of 3% of all limb fractures.[1,2] It is still contradictory whether a surgical procedure is necessary for humerus shaft fractures.[3] However, surgical procedure is recommended for severely displaced fractures, multiple fractures, segmental fractures, and fractures accompanied by vascular and neural injuries.[4,5] Complication rates are higher in patients who are treated by osteosynthesis through a conventional plate-screw system.[6] Continuous improvement in surgical techniques and fixation implants allowed the common use of intramedullary nailing (IMN) and locking compression plate (LCP) systems for internal fixation of humerus shaft fractures; there are studies demonstrating positive clinical effects of both.[7] However, several clinical trials on osteosynthesis performed through IMN and LCP showed conflicting results.[8–10] Small study samples included in previous studies emphasized that incoherent results may appear by suboptimal study quality and the inclusion of remote studies.[3] It was stated in another study that the effect of IMN on torsional forces was poor in cases where

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osteosynthesis was performed with IMN in femoral shaft fractures.[11,12] On the other hand, there is not any manuscript investigating the torsional force effect related to osteosynthesis performed with IMN and plate screw system in humerus shaft fractures.

The intensity of the osseous tissue as an alive tissue may change depending on the load exposed, and it is called Wolff's law.[13] The stability should be preserved along with the fracture line for healing of the fracture that appeared in the bones. Therefore, the fracture lines may be fixated through different implants. The factors affecting the fixation stability may include the fracture type, the stress shielding effect, and loading on the implants.[14,15] Stress shielding causes an intensity difference through the stress effect. The density increases in areas where load is transferred onto the bone and decreases in bone density in areas where no load is transferred. This is called the stress shielding.[12] The biomechanical effect of this causes a decrease in bone density in weak areas of the bone; this also causes failure of stability. Biocompatible materials are used in implants used for fracture fixations. The elasticity module of these materials is much more than the actual elasticity module of the bone.[12]

The essential during osteosynthesis is to achieve a stress distribution close to a healthy bone and to provide a load distribution similar to the physiological load flow. The stress shielding effect may be reduced in such fixations. Even if stability is ensured in cases where osteosynthesis is performed with a plate screw, insufficient compression and tension on the fracture surfaces cause delayed healing of the fracture line and this causes inadequate treatment.[16] It was observed in some previous studies that osteoporosis appeared in patients whose osteosynthesis was performed through plate screws.[17,18] This was stated as a decrease in stresses appeared and transferred to the osseous tissue.[19] Another previous study stated that the force transferred through IMN is reflected in the bone in patients who have had osteosynthesis through IMN. A certain stress thereby occurs at the fracture line and is positively reflected on the boiling. Furthermore, it was emphasized that the stress shielding effect would be less because of the load transfer on the bone with this method.[20]

In the present study, the plate screw system and intramedullary nailing method which are widely used in osteosynthesis in humeral shaft fractures were evaluated in terms of stress shielding through finite element analysis. Normal strain distributions on humeral models and maximum von Mises stresses on implants were investigated. Moreover, the assessment was done by considering the stress distributions on the fracture surfaces. As a clinical reflection, an evaluation was made of the recovery and rehabilitation process after surgery.

2. Material and method

Images were obtained by computerized tomography (CT) to create a 3D model of the humerus bone. After the CT images were transferred to the ANSYS 2021 R2 program (ANSYS, Inc., Canons-burg, PA), a transverse fracture model was created from the shaft region of the humeral bone meshed to the humerus bone and modeled in 3D (Fig. 1). The ethical approval was not taken for this study since it doesn't contain any human subjects.

Intramedullary nailing (IMN) technique and osteosynthesis were applied to the fracture models created with the plate screw system. The technique was applied through AO principles during the surgical procedure. Fixation was provided with a length of 240 mm and a diameter of 9 mm, with 3 screws on the distal part and 2 locking screws on the proximal side for the humerus nail. An 8-hole 3.5 mm plate was applied in the osteosynthesis with the plate screw system. The positioning of the fracture model created in the humerus bone was made according to the applications specified in the AO surgery reference 12. The SolidWorks program was used for the plate screw system created and the osteosynthesis model through IMN. The plate screw system applied to the humerus model is shown in Fig. 2a and the IMN system applied is shown in Fig. 2b.

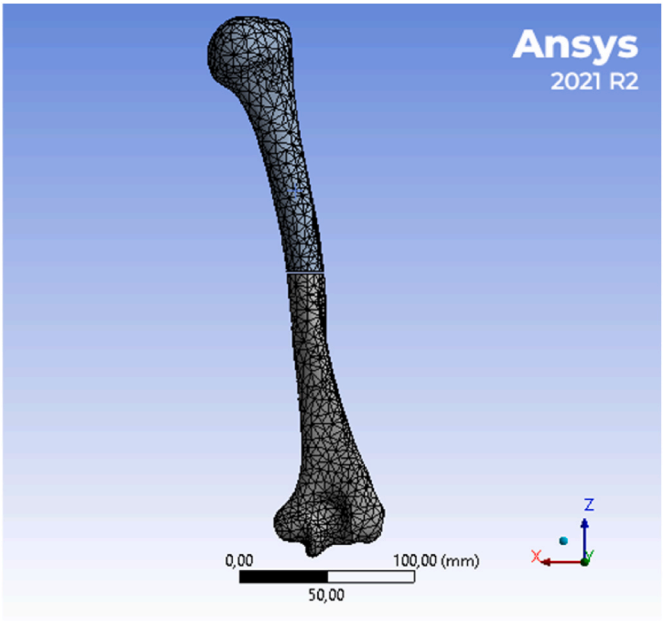


Fig. 1. A humerus bone with fracture model created.

The models were transferred to the Ansys Workbench program after positioning the designed models according to the surgical references.

The Ti6A14V material details were used for the properties of the implants used in our study. CT images were utilized for the humerus bone.[21] The material features used for finite element analysis were provided in Table 1.

All contact associations were determined as frictional in the finite element analysis. The friction coefficient between the bone and the screws was 0.42[23]; the friction coefficient on the implant and screws base was 0.2[22]; and the friction coefficient between the bone fracture surfaces was 0.37.[12]

The tetrahedron mesh structure was used for the finite element models in our study. The element size was chosen as 3.5 mm for the bone model and 2 mm for the plate and intramedullary nail models. Improvement was used for the mesh structure in all contact regions. The results were evaluated with the literature and the finite element models were validated. The node counts used were provided in Table 2.

As stated in the literature, 350 Nm force was applied to the humerus head after fixation of the humerus bone from the distal side.[24] The force directions and bone implant models applied are shown in Fig. 3. Fig. 3a, normal humerus bone; Fig. 3b, plated humerus bone; Fig. 3c, intramedullary nailed humerus bone.

3. Findings and discussion

In our study, the strain distribution on the humeral bone was examined to evaluate the stress shield effect. Furthermore, von Mises tensile forces were investigated to assess the risk of damage to the implants used. Since the stress values at the fracture sites are important in terms of fracture physiology and healing, the maximum von Mises stresses at the fracture line were also considered.

Maximum von Mises stress values and distributions in the humerus models created are presented in Fig. 4.

When we compared our study with the literature, similar results were obtained with other FEA studies. Values varying between 145 and 260 MPa were obtained on the nail in a previous study.[24] Values of 220 and 275 MPa were observed for the plate screw system applied.[25,26] Maximum stress values of 260 MPa on the nail and 280 MPa on the plate were detected in the present study. Similar values were observed in the results obtained from the intact humerus and femur.[27] These present

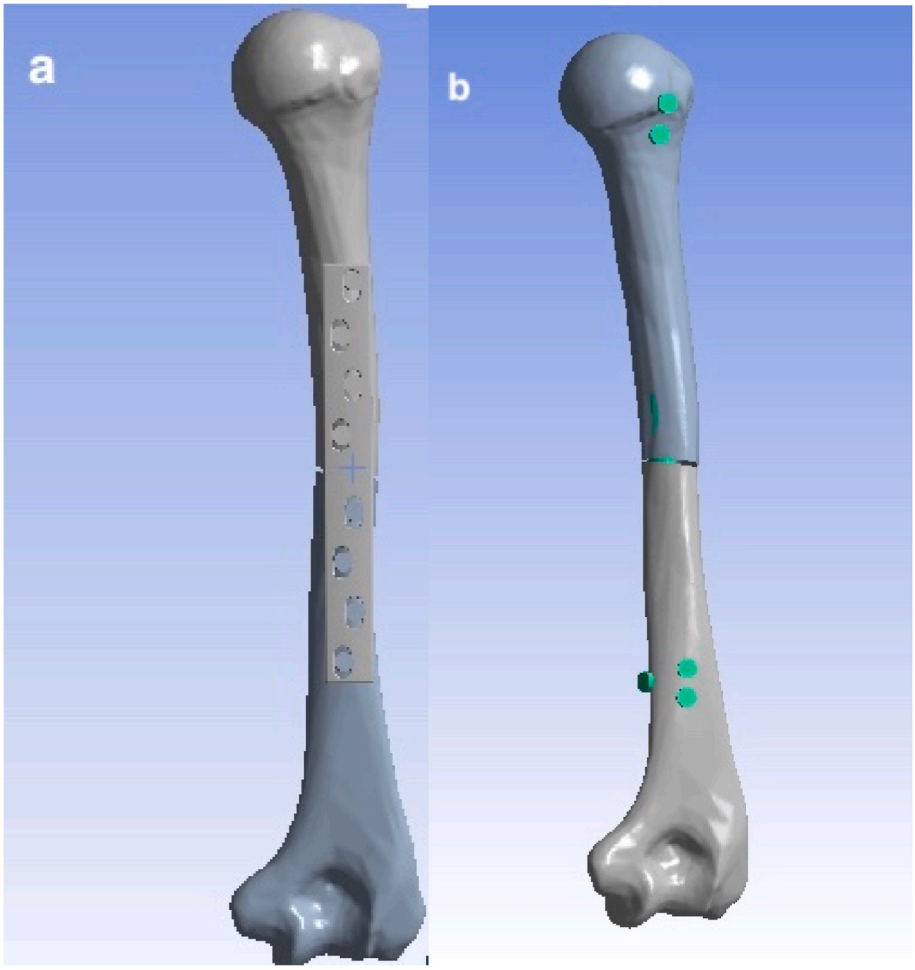


Fig. 2. A) The plate system applied onto the humerus; b) The IMN system applied to the humerus.

Table 1
Mechanical features of the materials used,[22] **φ** = density (g/cm^3), HU= Hounsfield unit.

Material	Density *(g/cm^3)*	Elasticity Module *(MPa)*	Poisson Ratio
Bone	$\varphi = 1.67 \times HU$	$0.004 \times \varphi^{2.01}$	0.3
Ti6Al4V	4.4	113000	0.33

Table 2
The node and element counts used in finite element models.

Model	Node	Element
Bone	91230	61350
Bone-Intramedullary nail	462578	311285
Bone-Plate	581352	370350

comparisons show that the result of our study is consistent with the literature.

The viscosity of the Ti6A14V material used in implants is 800 MPa, and the critical stress value for bone is 150 MPa in terms of damage.[28,29] No injury on the bone and implants is expected in either system according to the static loads applied in these study models. The maximum stress value applied in the intramedullary nail appeared on the middle section that was forced to bend, at the fracture line. Stress concentration was observed in the first screw in the proximal region on the plate. Although this is not a problem for static load in osteosynthesis with the plate screw system, it makes the implant failure in the screw more likely

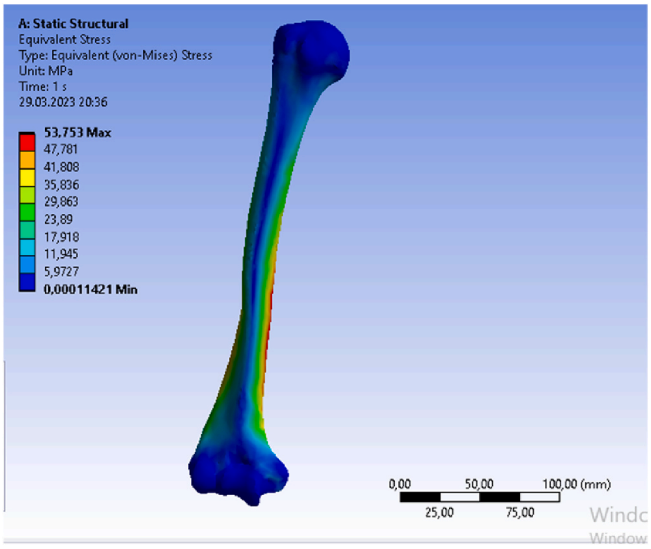


Fig. 3a. 350 Nm force was applied to the normal humerus bone.

under dynamic loads as the rehabilitation progresses. It was reported in the literature that screw damage occurred in the cases who had osteosynthesis through plate screw system after clinical trials.[30,31] If this situation persists and occurs, since stability cannot be achieved, it may prolong the treatment, especially during rehabilitation, and may even

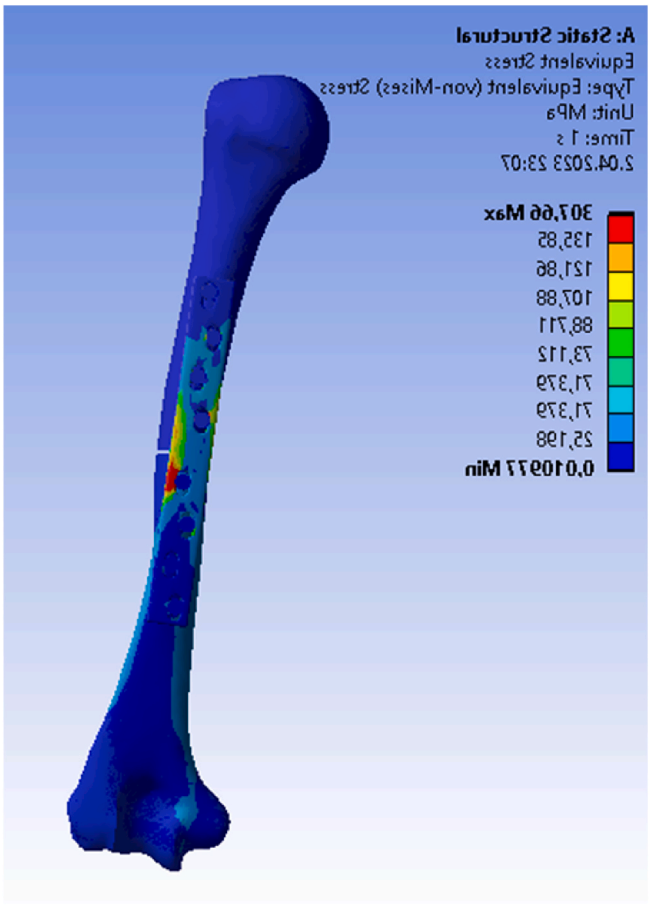


Fig. 3b. 350 Nm force was applied to the humerus bone with a plate applied.

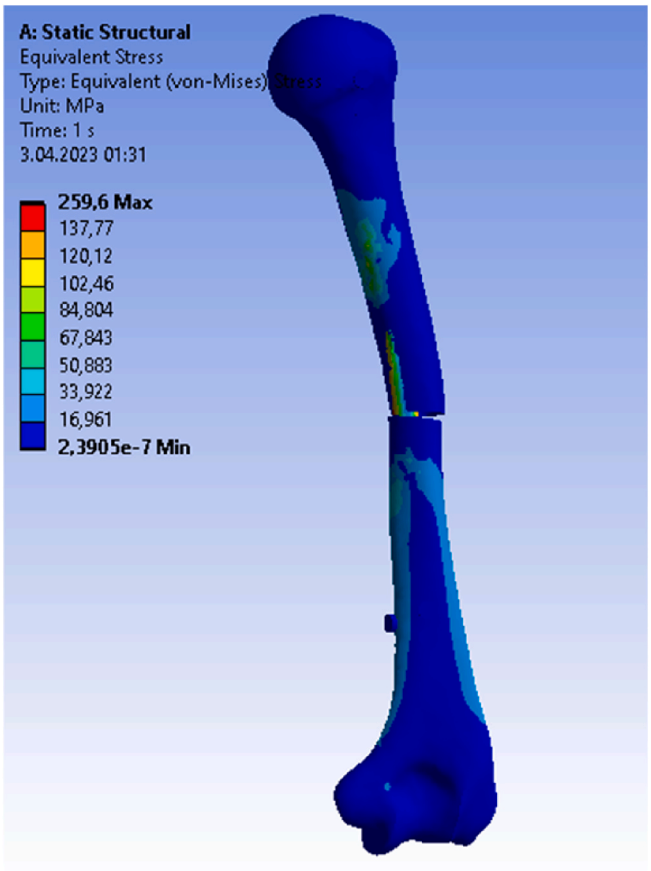


Fig. 3c. 350 Nm force was applied to the humerus bone with IMN.

result in unsuccessful treatment.

The stress values that appeared on the bones are not critical values for injury. However, implants used in fracture treatments reduce the load transferred to the bone, causing stress shielding formation.[32] The stress shielding condition has been studied in the literature with axial strain distribution.[33] In the present study, the stress distribution on humeral shaft fractures that underwent osteosynthesis with the intramedullary nail method was similar to the distribution on the intact humerus. Normal stress values on humeral shaft fractures performed by osteosynthesis with plate screw decreased. Therefore, the risk of stress shielding is more in osteosynthesis performed by plate screw. Since the stress shielding effect would cause bone weakening, it causes loosening on the screws used to fix the implants.[14,34] This may prolong the treatment duration, the rehabilitation and even cause treatment failure.

The implants used were evaluated mechanically in this study. Furthermore, the mechanical aspects of the implants are also evaluated. However, it was emphasized that biological factors are also important in fracture fixation surgeries. Less blood loss occurs with the plate screw system in the intramedullary osteosynthesis when compared to osteosynthesis. However, it was reported that more X-ray exposure could be observed.[35] However, complications of pulmonary embolism have been reported in osteosynthesis by intramedullary nailing. Therefore, there are manuscripts in the literature stating that osteosynthesis of humeral fractures should not be performed with IMN in the first place in patients with heart diseases.[36]

Comparison studies of implants may be detailed by adding different fracture types in future studies, determining the importance of biological and mechanical factors, scoring according to the coefficients to be created, and the superiority of the methods.

4. Conclusion

In this study, less stress values were obtained and stress concentrations were not formed on the implant in osteosynthesis performed by intramedullary nailing. Furthermore, normal strain distribution was obtained in the humeral shaft of the model fixed with an intramedullary nail, similar to that on the intact humerus. Therefore, the intramedullary nail fixation method was found more successful in terms of stability in humeral transverse fractures, both in terms of the possibility of damage to the implant and the effect of the tension shield that may occur on the humerus. This ensures a positive contribution to both the healing and rehabilitation process. The results of this study are valuable data for interested researchers and clinicians. The findings of this study may guide further studies for those focusing on it and may contribute to the development of a more comprehensive understanding of the topic.

5. Ethical

The ethical consideration is not relevant for this study. Because it is an experimental study including the finite element analysis and this study doesn't contain any human subjects. Therefore, any ethical approval was not taken.

Author's contributions

EA: Experimental procedures and manuscript writing.
MY: Evaluation of experimental results; FE: Literature review.
OMT: Literature review and manuscript writing.
MFA: Experimental procedures and data availability.
BA: Evaluation of experimental results and statistical analysis.
ZF: Manuscript revision and submission.

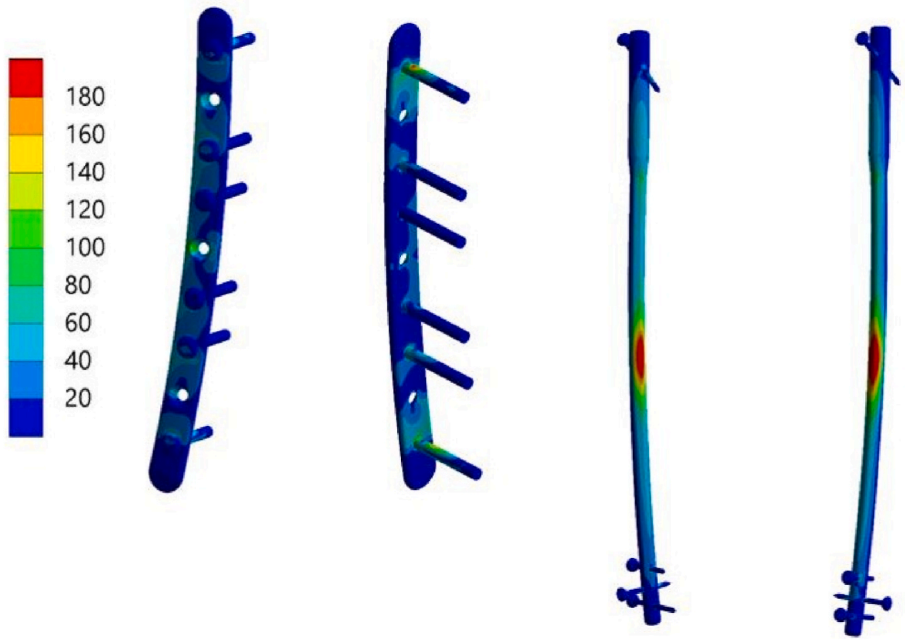


Fig. 4. Von Mises stress distributions in the plate screw and IMN.

AHO: Use of ANSYS workbench program.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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