

NUMERIC ANALYSIS OF BIOMECHANICAL PERFORMANCE IN THE FEMORAL NECK FRACTURE OF A BIOMATERIAL

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In this study, the biomechanical behavior of three different screw materials (Ti6Al4V, Magnesium AZ91 and Ti6Al4V-HA) was analyzed to fix the femoral neck fracture with triangular fixation under axial loading and it was investigated which material was better biomechanically. Geomagic Studio and SolidWorks software were used for three-dimensional (3D) process. The triangle configuration was preferred for femoral neck fracture. The computer-aided numerical analyses were carried out in AnsysWorkbench for two different materials. We believe that the fixation materials investigated may have a role in taking patients away from recurrent anesthesia and orthopaedic surgical risks.

Keywords: Femoral neck fracture; magnesium screw; finite element analysis; biomechanics.

1. Introduction

Biomaterials such as implants, drill bits, plates and screws used in orthopaedic and dental surgeries should be carefully selected in terms of stabilization and fracture healing process. Besides this, the biomechanical behavior of different materials used in these implants could affect the stability of the disease in which they are used in

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surgical procedures. The failure of implants can lead the patients to recurrent operations and this also increases anesthesia-induced mortality and morbidity especially in older patients.¹⁻⁴ Globally, there were 178 million new fractures in 2019, with 455 million cases of common acute or long-term fracture symptoms reported. 25.8 million of them mentioned as “years lived with disability of fractures”.⁵ For this reason, successful fracture management becomes a more important issue as many factors are related like fixation materials for stability. In the literature, there are various studies on implant design, implant materials and fatigue behavior in the skeletal system or dentistry. Sykaras *et al.*⁶ reviewed the literature on materials, designs, and surface topographies of endosseous dental implants. Three-dimensional analysis of the mechanical interaction between a femoral stem and the femur in a hip arthroplasty was performed.⁷⁻⁹ In another study,¹⁰ three-dimensional finite element model for fatigue analysis of the hip implant was used.

Senalp *et al.*¹¹ modeled four stem shapes of varying curvatures for hip prosthesis. Static, dynamic and fatigue behavior of these designed stem shapes were analyzed using commercial finite element analysis code ANSYS. It also investigated the static, dynamic and fatigue behaviors of the implants by Kayabasi *et al.*¹² Gok and Inal¹³ investigated the best stable fixation application by applying five different screw configuration types in a femoral neck fracture model using the FEA method. In this study, the biomechanical behavior of three different screw materials (Ti6Al4V, Magnesium AZ91 and Ti6Al4V-HA) was analyzed to fix the femoral neck fracture with triangular fixation under axial loading and it was investigated which material was better biomechanically.

2. Material and Method

The human femur model (Fig. 1) and M6.5 cancellous screw were scanned using a 3D scanner and a point cloud was obtained (Fig. 2). This point cloud was converted into a 3D femur model and a 3D screw using the Geomagic Studio program. The femoral

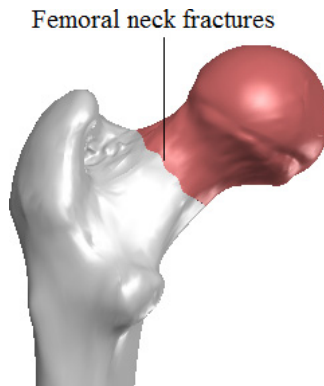


Fig. 1. The femoral neck fracture.¹³

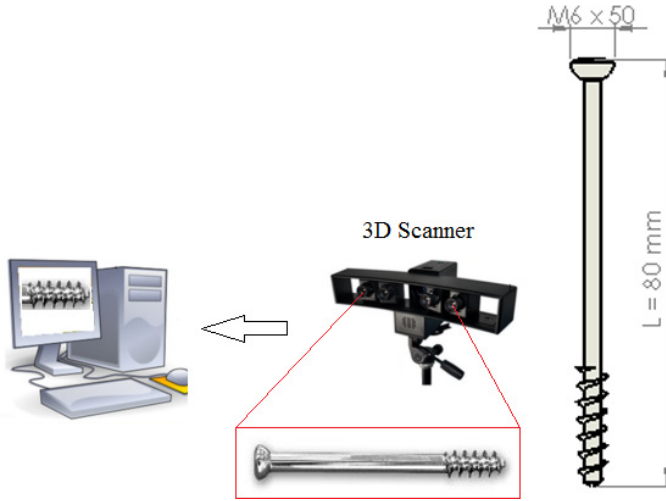


Fig. 2. Scanning of the femur model and screw with a 3D scanner.

neck fracture was modeled using the SolidWorks program for triangular configuration only (Fig. 3). In this study, M6.5 screws (M6.5 × 16 mm for cancellous bone) were used to fix the femoral neck fracture. Computer-aided numerical analysis of two different materials was carried out using AnsysWorkbench finite element analysis program. Loading, boundary conditions and material properties were defined, and finite element analyses were used to calculate and solve and the stresses on the implant screws, the stress on the fracture line, the gap, the penetration and the shear distance. In addition, SEM (microstructure pictures) and EDX (element contents) values of both Ti6Al4V and AZ91 materials were obtained. SEM and EDX pictures

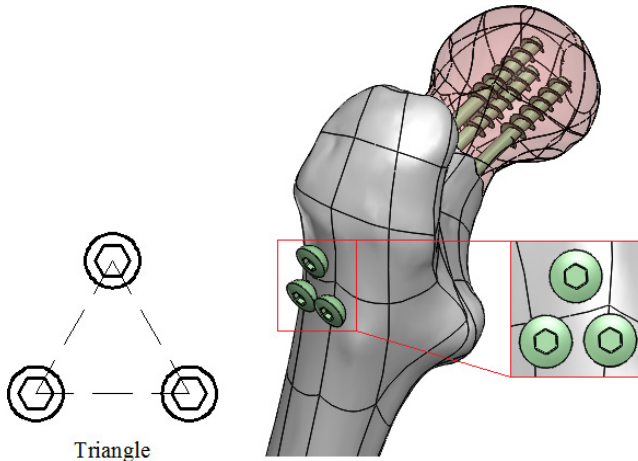
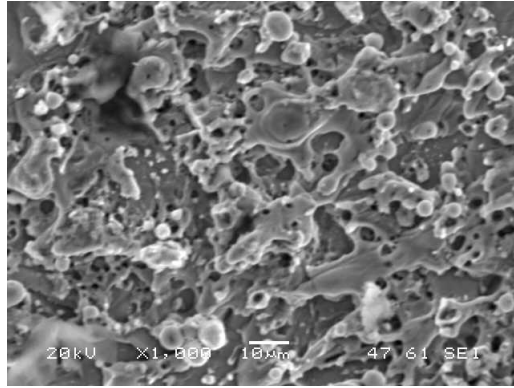
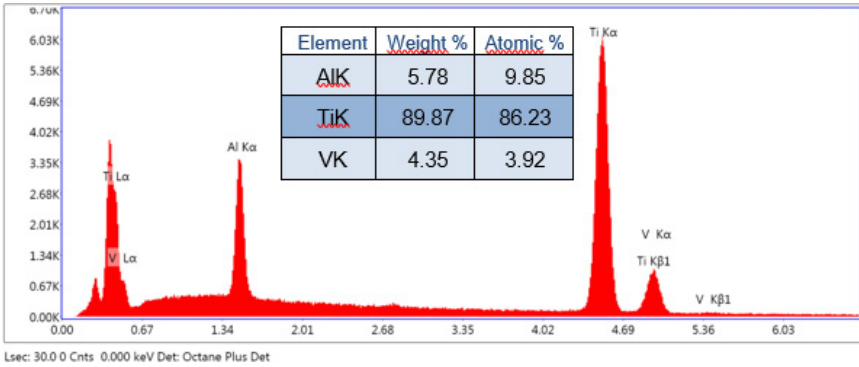


Fig. 3. Triangle configuration used to fix the femoral neck fracture.

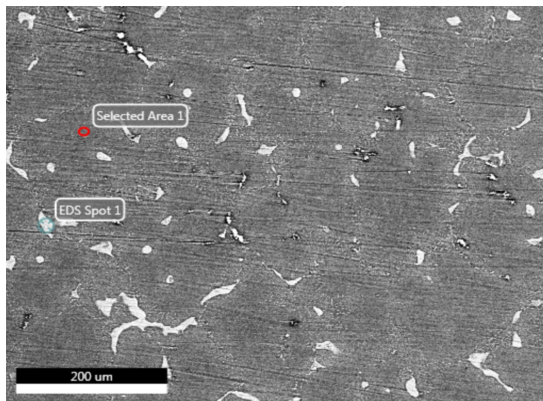


(a)



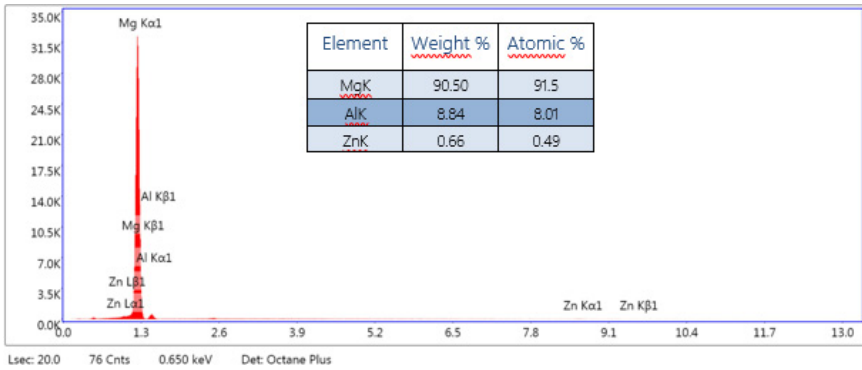
(b)

Fig. 4. Ti6Al4V, (a) SEM, (b) EDX.^{14,15}



(a)

Fig. 5. Mg AZ91, (a) SEM, (b) EDX.¹⁶



(b)

Fig. 5. (Continued)

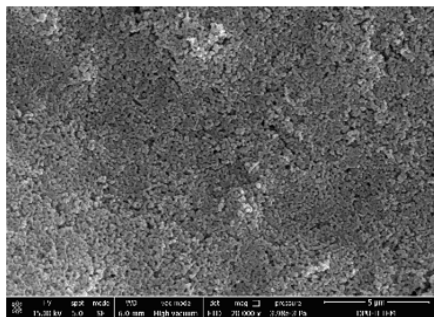
Table 1. Mechanical properties of bone and screws used in SEA.¹⁷⁻²⁰

Parameters	Magnesium AZ91	Ti6Al4V	HA Coating	Bone
Density ($\text{kg} \cdot \text{m}^{-3}$)	1,840.0	4428.78	3100	2100
Elasticity modulus (GPa)	45	104.800,31	7-13	17
Tensile yield strength (MPa)	140.0	827,37		135
Tensile ultimate strength (MPa)	230.0	1050	38-48	148
Poisson ratio	0.35	0.31	0.27	0.35

of Ti6Al4V and Mg AZ91 materials are given in Figs. 4-5. The mechanical properties of the materials are given in Table 1.

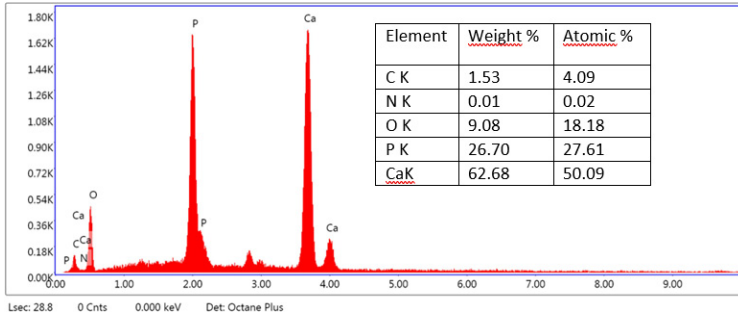
2.1. Loading and boundary conditions

The mesh process was performed using tetrahedron finite element for the FEA modeling after importing five different configurations of 3D models into the



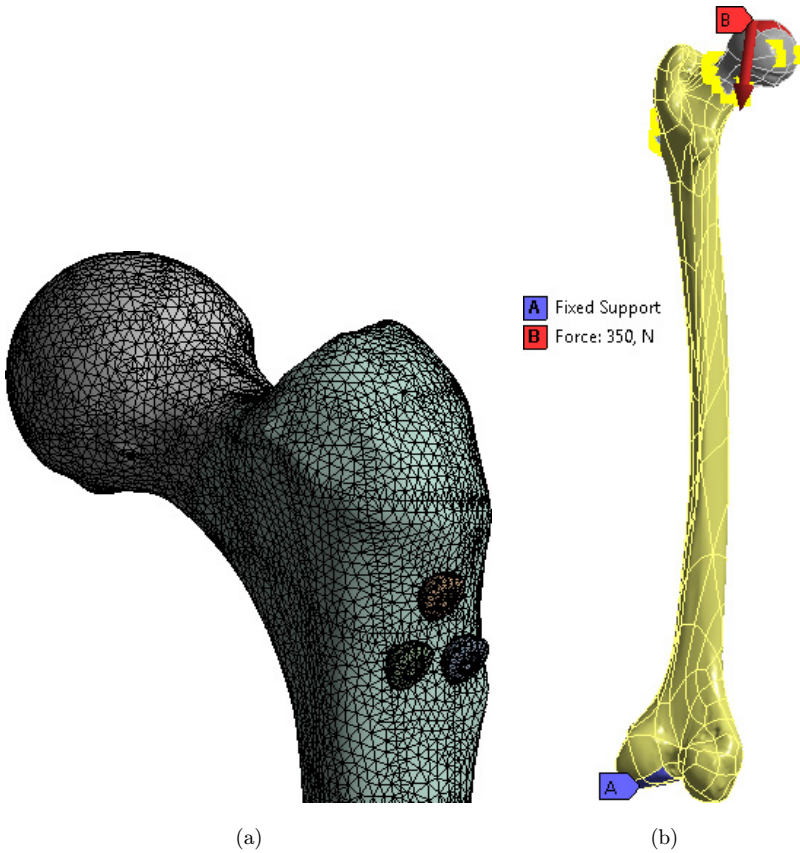
(a)

Fig. 6. Ti6Al4V-HA, (a) SEM, (b) EDX.



(b)

Fig. 6. (Continued)



(a)

(b)

Fig. 7. Mesh structure of triangle configuration (a), loading and fixing (b).

AnsysWorkbench software. The FEA model has 285,156 nodes and 166,231 elements. The mesh size was input as 1 mm for the full 3D model, as seen in Fig. 7(a). A load of 350N in the axial direction was applied to the femoral head, and it was fixed from the distal condylar articular face, as seen in Fig. 7(b). Contact types between bone–bone interaction and screw–bone interaction were defined as a frictional contact. Friction coefficients were taken as 0.46 for bone–bone interactions and 0.42 for screw–bone interaction.²¹ The convergence analysis was conducted, as seen in Fig. 8.

3. Results

The results (gap, penetration and sliding distance values occurring in the fracture line) obtained from the computer-aided numerical analyses are given in Tables 2 and 3. Figure 9 shows the stresses occurring at screws.

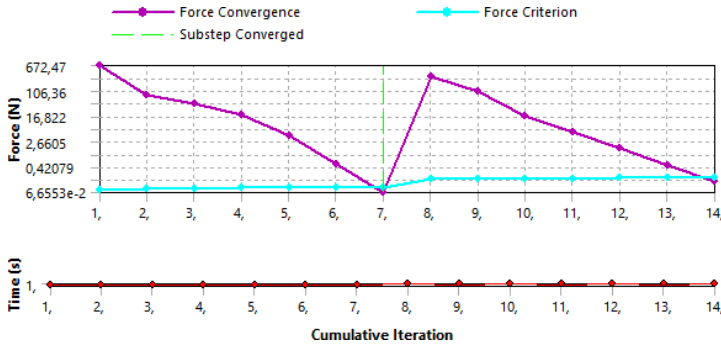


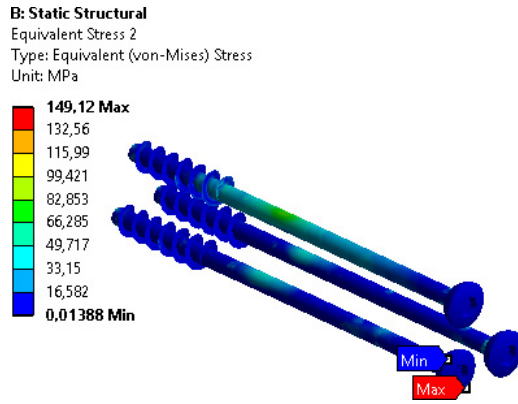
Fig. 8. Convergence analysis.

Table 2. Deformation values of screws.

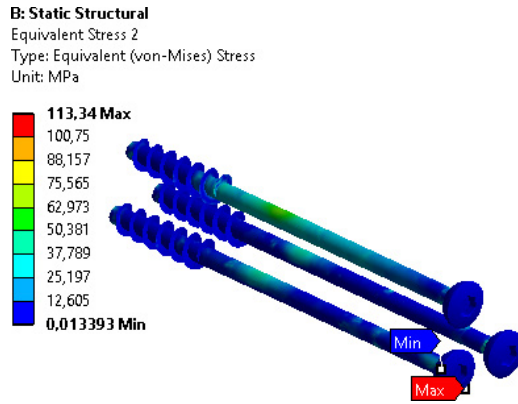
Screw material	Deformation values (mm)
Ti6Al4V	3,6329
AZ91	3,6621
Ti6Al4V-HA	3,6326

Table 3. Stress and deformation values in bones and screws.

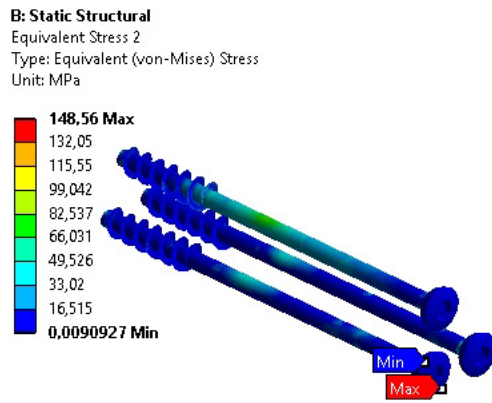
Screw material	Stress distributions				
	Screw stress (MPa)	Fracture line (MPa)-upper -lower	Gap (mm)	Penetration (mm)	Sliding distance (mm)
Ti6Al4V	149.12	20.95–32.64	0,036672	0,0028687	0,00245
AZ91	113.34	27.70–38.06	0,062408	0,0031284	0,0033489
Ti6Al4V-HA	148,56	20,87–32,66	0,036427	0,0028631	0,0024398



(a)



(b)



(c)

Fig. 9. The stress distribution for the screws, (a) Ti6Al4V, (b) AZ91, (c) Ti6Al4V-HA.

4. Conclusion

When the result of the finite element analyzes are examined, the stress on Ti6Al4V-HA screws is lower than the stress on the Ti6Al4V screws. However, AZ91 screws have the lowest stress. The other values are very close to each other, This suggests that AZ91 magnesium alloy can be used as an alternative biomaterial to titanium due to its advantages such as density, low cost, and easy manufacturing.

Since magnesium alloys can easily corrode in the body, they attract a lot of attention in medical applications. Its components, which are formed after magnesium corrosion, are bio-safe and can be easily removed from the body. Magnesium alloys are used in braces and plates to fix broken bones. Magnesium alloy implants have superior strength-to-weight ratio as well as good biodegradability compared to other implants. However, the degradation rate of magnesium alloy implants should be well controlled and used in appropriate treatment methods.

Since the low yield strength of AZ91 magnesium alloy is a disadvantage, it is recommended to be used in situations that do not require any movement or where low loads are applied. In addition, the mechanical properties of AZ91 magnesium alloy can be improved by applying different heat treatments or strength-enhancing alloying elements.

The other contact values formed at the bone fracture line using Ti6Al4V screw and Ti6Al4V-HA screws are very close to each other. Especially, this shows that the mechanical properties of the HA coating are very close to the bone and the positive effect of the coating process.

There are several papers available about fatigue failure of the titanium or magnesium screws. The failure occurred due to repeated loading with reduced stress values, even under the yield stress and strength limit values, with stress concentrated at the site of the screw's changing shape design. No material defects were observed, and the design and technical implementation of the implant were considered sufficient according to several other authors. The development of pseudo-arthritis preceding the screw breakdown can also be considered a result of poor technical implementation of osteosynthesis. We believe that the basic assumption is the healing of stable pertrochanteric fractures and preventing the breakdown of the sliding screw due to appropriately implemented osteosynthesis from a technical point of view with correct repositioning of the fracture and placement of the implant.²²

We believe that all the materials used in such implants can be investigated before any surgical attempt in terms of fracture stability or others to prevent the patients from recurrent risk of anesthesia and orthopedics.

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