Fatigue behaviors of different materials for schanz screws in femoral fracture model using finite element analysis

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In the daily life, human beings may be met with a number of undesired traumas. As a result, intertrochanteric fractures can occur in the skeletal system. Intertrochanteric femoral fractures are serious traumas that can lead to pneumonia, pulmonary embolism or death. Therefore, fixing as accuracy and stabilty of these fractures is necessary. The schanz screws with pertrochanteric fixator body are used for stabilizaiton of intertrochanteric fractures. Fatigue behaviors of the schanz screws must be longer than the duration of fracture consolidation. The aim of this study is to determine whether there are differences between fatique behaviours of different materials for schanz screws when they are used for intertrochanteric femoral fracture fixation. Fatique behaviors of schanz screws used for fixing of intertrochanteric fractures were analysed with ANSYS Workbench software using finite element analysis under dynamic loads for stainless steel and titanium. After the analysis, minimum fatigue life has been determined as approximately 21 months for the schanz screws having stainless steel while titanium has been determined as approximately 2 months. In addition, safety factor for schanz screws having stainless steel is calculated as 1.36 whereas safety factor for titanium is calculated as 1. Therefore, considering the consolidation of an intertrochanteric femoral fracture with a mean duration of three months, the titanium schanz screws shouldn't be used since their fatigue behavior is two months and safety factor is less than stainless steel.

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1. Introduction

People are particularly encountered to undesired traumas with advancing age. As result of undesired traumas, intertrochanteric fractures may occur in the musculo - skeletal system. Intertrochanteric femoral fractures are serious traumas that can lead to injuries, pneumonia, pulmonary embolism or death. Therefore, fixing as accuracy and stabilty of these fractures is necessary. The schanz screws with pertrochanteric fixator body or various implants are used for stabilization of intertrochanteric fractures. Implants used for fixation of fractures such as pertrochanteric fixators (PTFs) are subjected too much forces during walking. Variable stresses are occurred due to these forces on the implants. The amplitude, periodic changes and repeat of these stresses instead of the maximum values are very important in terms of material life and safety. Periodically, varying stresses lead to a set of cracks and wears in the internal structure of implant material. The cracks occurring in the internal structure of implant material or at the any sharp corner under the repetitive forces lead to stress accumulations with time. As a result, implant material may be damage even at a lower its yield strength. One of these implant materials are the schanz screws of external fixators used to fix bone fractures. Intertrochanteric fractures (ITFs) are among these fractures which are serious traumas and usually seen in the older age. They can lead to morbidity or mortality [1]. The major goal of ITFs surgery is to ensure stabilization that enables the safe movement and loading on the fracture in reduction position. Thus, it is possible to grant the patient for early ambulation and rehabilitation [2, 3]. For this reason, the fatigue behaviors of different materials for schanz screws of external fixator used for fracture stabilization should be determined. In the literature, several studies are presented about the implant design and fatigue behavior in the skeletal system or dental. Three-dimensional analysis of the mechanical interaction between a femoral stem and the femur in a hip arthroplasty was performed [4-6]. In another study, [7] three-dimensional finite element model for fatigue analysis of the hip implant was developed. Senalp et al. [8] 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. In parallel to this study, Kayabasi et al. [9] investigated the static, dynamic and fatigue behaviors of the implants. They applied dynamic loads on occlusal surface for five minutes. Fatigue life of the implants was calculated based on Goodman, Soderberg, Gerber and mean-stress fatigue.

The schanz screws with PTFs are used for fixation of ITFs. The fatique behaviors of schanz screws are very important for implant failure. If the implant failure occurs, the consolidation of fracture may delay or be off. Fatigue behaviors of the schanz screws must be longer than the duration of fracture consolidation. According to our knowledge, there is no any study about fatigue behaviors of schanz screws of PTFs in the literature when they are used for ITFs fixation. The aim of this study is to determine whether there are differences between fatique behaviours of different materials for schanz screws.

2. Computer aided 3D modeling

The human femoral model is scanned using 3 dimension (3D) scanner and point cloud is obtained. After that, 3D model of femur is created using point cloud data by Geomagic Studio 10 program. Modeling the femoral intertrochanteric fracture is created using SolidWorks program as seen in Fig. 1. The modeling of the implants is also modeled in 3D using the SolidWorks program. These models are imported into the ANSYSWorkbench to prepare the Finite Element Analysis (FEA) and the mesh generation.

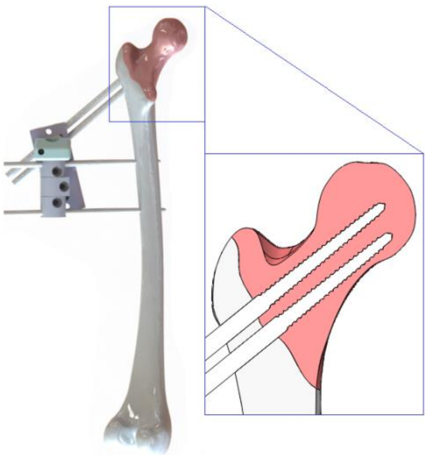


Fig. 1. Femoral intertrochanteric fracture model fixed with pertrochanteric fixator.

3. Computer aided finite element analysis modeling

FEA has been used in orthopedic biomechanics as an important design and analysis tool of optimal implant design, total joint replacements, bone drilling and other orthopedic devices. A commercial finite element based program, AnsysWorkbench is used to investigate the fatigue behaviors of schanz screws used for intertrochanteric fractures. FEA model is considered as Isotropic Elasticity of Linear Elastic. The mesh generation of the models is created using the tetrahedrons element type as seen in Fig. 2. The generated finite element model has 147783 nodes and 96290 elements. While the element size of the model is selected as 4 millimeter (mm), the contact regions are selected as 2 mm.

3.1. Loading and boundary conditions

The femur is fixed from the distal condylar articular face. PTFs fixation is performed similar to the surgical implantation technique used in routine orthopedic surgeries. Contact types among the parts of the implants and bone are defined as a frictional contact. These contact interactions are assumed between the different parts of the models. Friction coefficients are taken as 0.46 for bone–bone interactions and 0.42 for bone–implant interactions [10]. For static analysis, the screw holes of body fixator are constrained and showed as label A in Fig. 3. A load of 3 kiloNewton (kN) with an angle of 20° is applied to the femoral head as showed as label B in Fig. 3. This study is performed according to a person of 70 kilogram (kg). [11]. An abductor muscle load of 1.25 kN showed as label C in Fig. 3 is applied at an angle of 20° to the proximal area of the greater trochanter. Distal end of the femur is constrained not to move in horizontal direction showed as label D in Fig. 3 [8; 12]. An iliotibial-tract load of 250 N showed as label E in Fig. 3 is applied to the bottom of the femur in the longitudinal femur direction. All materials used for PTFs were stainless steel from the ANSYS Material Library.

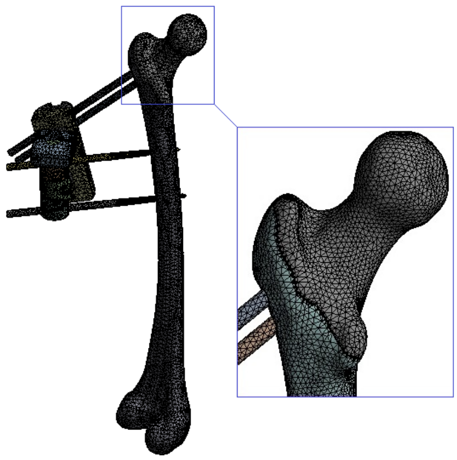


Fig. 2. Mesh structure of pertrochanteric fixator and femoral intertrochanteric fracture.

Fig. 3. Forces acting on the pertrochanteric fixator and femur.

3.2. Material models

The biomechanical properties of implants and bone used in the FEA are summarized in Table 1. Three different materials for schanz screws were used in the fatigue analysis. These materials were stainless steel and titanium. Linear isotropic material model was used for behaviors of implant materials and bone. The alternating stress versus number of cycles (S–N curve) for schanz screw materials used in this study for fatigue calculations was given in logarithmic scale in Fig. 4.

Table 1. Biomechanical properties of femur bone and schanz screws [13; 14].

Material	Density (kg/m^3)	Young's modulus (GPa)	Tensile Yield strength (MPa)	Tensile Ultimate strength (MPa)	Poisson's ratio
Stainless steel [13]	7750	193	207	586	0.31
Titanium [13]	4620	96	930	1070	0.36
Bone [14]	2100	17	135	148	0.35

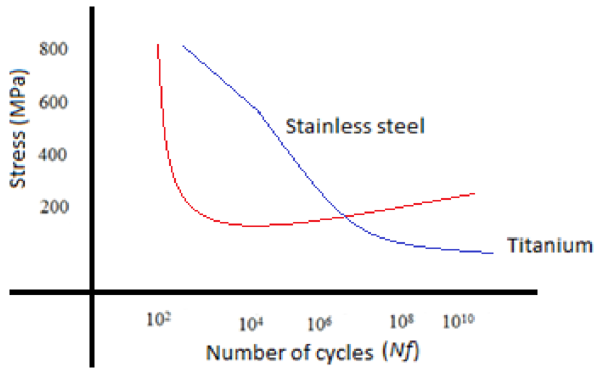
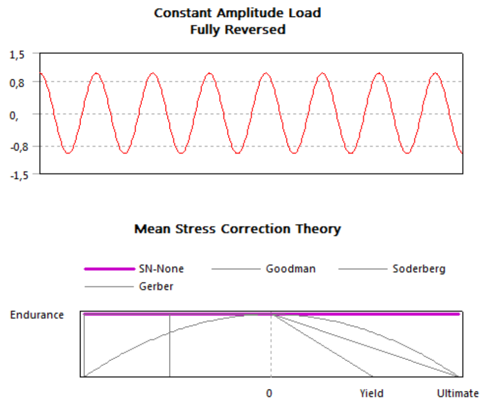


Fig. 4. S–N curves of schanz screws made from stainless steel and titanium [15].

3.3. Fatigue analysis

In this study, fatigue analyses were conducted upon based on Equivalent (von-Mises) stress using ANSYS Workbench. Equivalent stresses were obtained for stainless steel and titanium schanz screws. Fatigue life is selected as analysis type and fully reversed is selected as loading type (Fig. 5a). Any mean stress theory is not selected due to use Constant Amplitude Load and Fully Reversed loading type for analyses. In order to predict the fatigue life of the schanz screws, design life is selected as 10^9 seconds. Convergence analysis was conducted as seen in Fig. 5b.



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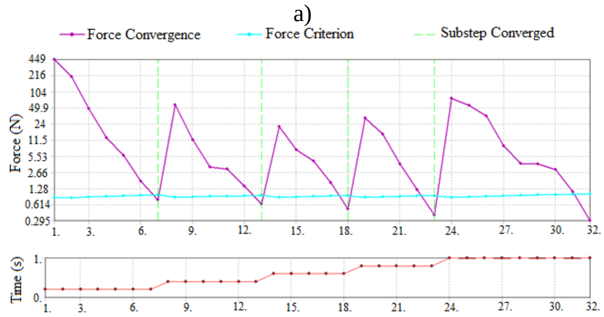
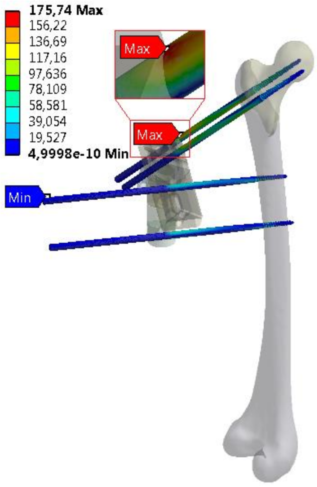


b)

Fig. 5. a) Fully reversed for loading type and mean stress theory [13] (AnsysWorkbench Material), b) Convergence analysis.

4. Results and discussion

The biomechanical properties of the materials for each component were identified and analyses were solved. From the analyses, the maximum equivalent stresses were obtained from the upper schanz screws just in front of the fixator body having stainless steel as seen in Fig. 6. The maximum equivalent stress is obtained about 175.74 MegaPascal (MPa) for schanz screws having stainless steel, while the maximum equivalent stress is obtained 194.49 MPa for titanium.



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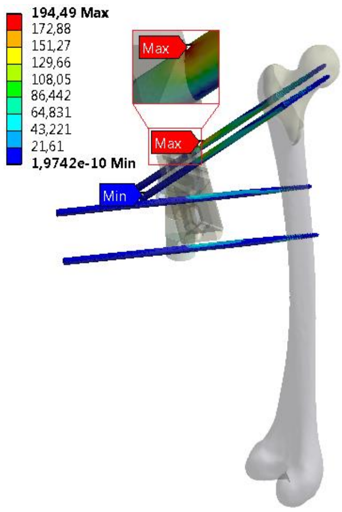
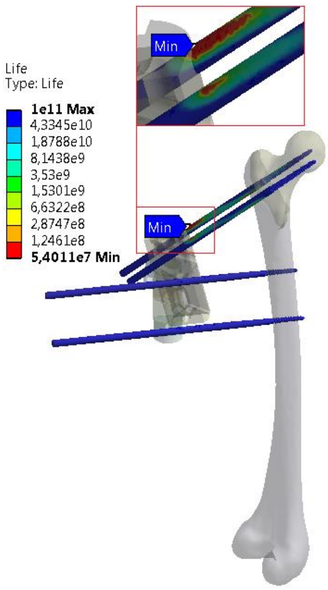


b)

Fig. 6. The maximum equivalent stresses of schanz screws, a) stainless steel, b) titanium.

As a result of fatigue analysis, minimum fatigue life has been determined as 5,4011e+007 seconds (approximately 21 months) on the upper schanz screws just in front of the fixator body having stainless steel while schanz screws having titanium has been determined as 5,9049e+006 seconds (approximately 2 months).

Titanium offers a lower modulus of elasticity, ductility and fatigue properties according to stainless steel [12; 15-18]. Although the each material that have properties depend on the specific alloy composition are not significant within the physiologic range of forces in the surgical differences, the titanium is susceptible to early failure when it is excessively bend or deformed before insertion. On the contrary, stainless steel is intriguing as implant material. Because of it has highest strength and middle yield. At the same time, it is almost low in cost, has high machinability, and maintains a high ductility. But titanium is expensive, has low machinability, and sensitive to external stress risers (scratches), which can dramatically shorten its fatigue life. Stainless steel has favorable fatigue characteristics in the relatively low cycles, but in the higher cycles titanium alloy is more resistant to fatigue as seen in Fig. 4 [15].



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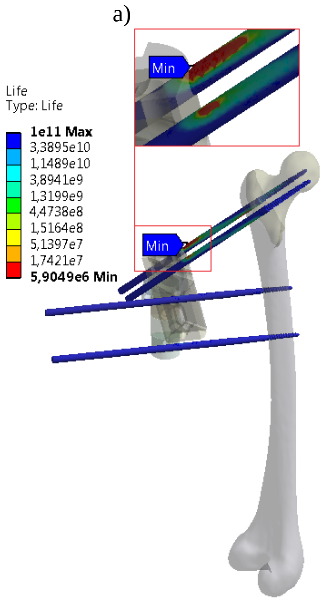

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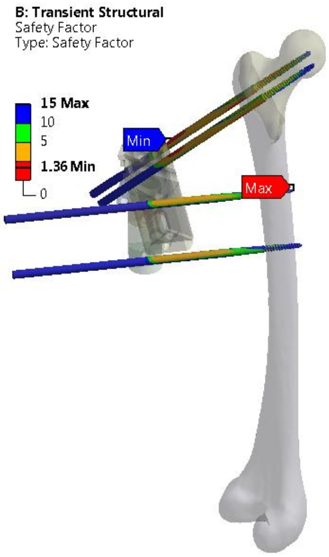
Fig. 7. The fatigue life of schanz screws, a) stainless steel, b) titanium.

As seen in Fig. 8, safety factor for schanz screws having stainless is calculated as 1.36 whereas titanium is calculated as 1. Safety factor for schanz screws having stainless is higher than titanium. This means schanz screws having stainless are better and higher fatigue lives than titanium under dynamic loading.



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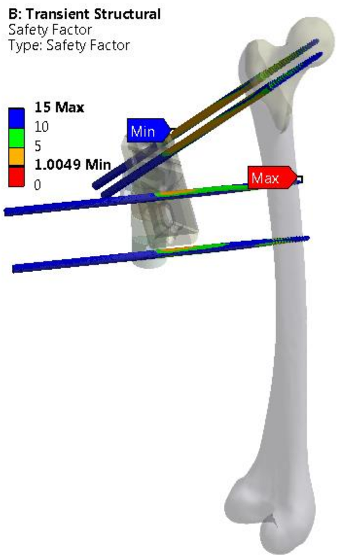

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Fig. 8. The safety factor of schanz screws, a) stainless steel, b) titanium.

5. Conclusion

The fatique behavior and safety factor of schanz screws are very important for implant failure when they are used for ITFs fixation. If the implant failure occurs, the consolidation of fracture may delay or not happens. According to our results, fatigue life and safety factor of schanz screws having stainless steel is higher than titanium. Therefore, considering the consolidation of an ITF with a mean duration of three months, the titanium schanz screws shouldn't be used since their fatigue behavior is two months and safety factor is less.

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