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ORIGINAL ARTICLE

Using as Screw of PEEK in Femur Neck Fractures as an Alternative Biomaterial

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Abstract Titanium screws used in femoral neck fracture fixation may lead to issues such as stress shielding and localized stress concentration. This study investigates the feasibility of using polyether-ether-ketone (PEEK) screws arranged in a triangular configuration as a potential alternative. Mechanical performance, biocompatibility, and load-bearing capacity are significant for these applications. Finite element analysis (FEA) revealed that PEEK screws exhibited a lower insertional stress of 92.26 MPa but experienced higher fracture line stress (79.96 MPa), gap (0.50 mm), and penetration (0.0074 mm), indicating increased micromotion. The calculated safety factor was 1.0297, which is adequate for average patients but may not ensure safety under high-load conditions. Compared to titanium, PEEK offered improved stress distribution and fatigue resistance but also demonstrated mechanical limitations. Overall, PEEK screws show promise as a bioinert and radiolucent alternative in orthopaedic applications, yet further optimization is needed for broader clinical adoption in high-demand scenarios.

Keywords PEEK · Finite element analysis · Biomaterial · Biomechanics · 3D printing

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1 Introduction

Polyether-ether-keton (PEEK) is an engineering plastic which has known high performance, outstanding mechanical and chemical strength properties. It is widely used in challenging industries such as automotive, aviation, medical, and electronic. Considering advantages and development potential as a biomaterial of PEEK, especially it can be said that it offers a strong alternative to titanium for bone implants and dental applications. It will be more preferred in the future using surface engineering and biocompatibility enhancing coatings. Additionally, positive outcomes provide in terms of surface modification, osseintegration, and customized manufacturing using 3D printing technology which makes it valuable for both medical and industrial applications.

Polyether-ether-ketone (PEEK), a semi-crystalline thermoplastic polymer from the poly-aryl-ether-ketone family, was first developed in 1978 [1]. Its structure, composed of benzene rings, ketone, and ether groups, ensures heat resistance, stability, and a balance between rigidity and flexibility [2]. PEEK exhibits high chemical resistance, biocompatibility, bioinertness, and excellent mechanical properties [3]. Compared to biomedical metals like 316L stainless steel, titanium alloy, and tantalum, PEEK offers advantages: its mechanical properties (density: 1.28–1.32 g/cm^3, flexural modulus: 3 GPa, flexural strength: 110 MPa) closely match human bone, minimizing stress shielding [4]. It is also radiolucent and nonmagnetic, preventing interference with CT and MRI scans. Additionally, its thermal conductivity (0.29 W/m/K) is closer to human cortical bone (0.68 W/m/K) than Ti6Al4V, reducing discomfort from thermal mismatch [5–7]. These attributes position PEEK as a promising alternative to titanium alloys for orthopaedic implants.

Consistent with previous studies, PEEK offers advantages in terms of biocompatibility and the absence of metal ion release. However, its propensity for higher deformation and limited load-bearing capacity poses challenges for long-term clinical performance, necessitating additional mechanical reinforcements or surface modifications, particularly for patients subjected to substantial mechanical loads. Yamaji et al. [8]. reported that large micromotions within small gaps at the fracture site could have a positive impact on fracture healing. In the present study, the gap interval values of the implant were found to be relatively high; however, this remains within safety limits. Notably, none of the existing studies have reported gap intervals exceeding 6 mm [9].

In addition, as determined in the study by Klein et al., considering the implant technique applied in the appropriate position and the appropriate amount of movement between fragments that it provides causes a strong callus formation, correct positioning of the implant will be an advantage in fracture detection [10]. In the study conducted by Wallace et al., a fourfold increase in corticomedullary blood flow was detected in the fixator group that was applied to the osteotomy area and allowed micromovements, two weeks after osteotomy, and it was shown that micromotion supported the healing of experimental fractures. We believe that the increased corticomedullary blood flow, which has been found to increase in the treatment of femoral neck fractures, where circulatory problems are considered to be one of the most important factors in terms of fracture healing, may be positively reflected by the greater fracture line load that our implant will detect [11]. Aro et al. evaluated the effects of fracture type and stability on fracture healing and callus formation. The authors stated that physiological load and fracture spacing are the most important factors in callus formation [12]. If it is believed that the implant may cause increased load on the fracture line and PEEK has been chosen due to its significant advantages, the gradual increase in load-bearing from low to high during the postoperative period, along with regular clinical and radiological follow-ups, can help manage this potential risk more safely. Kennedy et al. [13] determined the material with the most appropriate biomechanical performance by comparing the flexural strength, stiffness, and load-carrying capacity of carbon and glass fiber-reinforced PEEK intramedullary femoral nails produced by 3D printing with experimental and numerical analyzes. Molinar-Díaz et al. [14] revealed the difficulties encountered in the production of PEEK and fiber-reinforced PEEK composites to be used as implants, and to evaluate the biocompatibility and clinical application potential of multifunctional PEEK biomaterials developed with reinforcements such as carbon fiber (CF), hydroxyapatite (HA), and titanium dioxide (TiO_2). Miranda et al. [15] investigated the mechanical behavior of PEEK samples produced by fusion deposition modeling (FDM) method, to evaluate the differences between heat-treated and untreated samples and to reveal the effect of heat treatment on the mechanical performance of PEEK for use in medical devices.

This study aims to evaluate the feasibility of using polyether-ether-ketone (PEEK) screws in a triangular configuration as an alternative to titanium for the fixation of femoral neck fractures. By analyzing the mechanical performance, biocompatibility, and load-bearing capacity of PEEK screws, the study seeks to determine their potential advantages in terms of stress distribution, fatigue resistance, and reduced risk of stress shielding compared to titanium. The findings will contribute to the development of alternative biomaterials for orthopaedic applications, particularly in fracture fixation.

2 Material and Method

This study aims to investigate the biomechanical performance of PEEK an alternative biomaterial to titanium in fixing femoral neck fractures (Fig. 1) using triangular fixation under compressive loading. Screw configurations determine the placement of screws in femoral neck fracture repair. Choosing this configuration is based on the fracture type, stability, and required load-bearing capacity for their options such as triangular, parallel, or dynamic hip screw designs. In this study, triangular configuration was chosen due to having the best biomechanical performance and the most stable fixation method for femoral neck fractures such as earlier studies [16, 17]. To stabilize the femur neck fracture was used M Ø6.5 cancellous bone screw, pitch 2 and 16 thread, shaft 5, and core 4.5 mm.

2.1 Loading and Boundary Conditions

The FEA modeling in ANSYS Workbench utilized tetrahedral elements, with five different 3D models imported (Fig. 1). The model comprised 285,156 nodes and 166,231 elements, with a mesh size of 1 mm. A 350-N axial load was applied to the femoral head, while fixation was maintained at the distal condylar articular face. Frictional contact was defined for bone–bone and screw–bone interactions, with friction coefficients of 0.46 and 0.42, respectively [18]. This study exclusively involved computer-aided numerical analysis, with coating material properties obtained from the literature. To ensure reliability, the analyses were repeated three times.

According to mesh metric developed by ANSYS, Inc [19], mesh quality is very important in terms of reliability of the results. Low orthogonal quality or high skewness values are not recommended. Generally, try to keep minimum orthogonal quality > 0.1, or maximum skewness < 0.95. However, these values may be different depending on physics and the location of the cell.

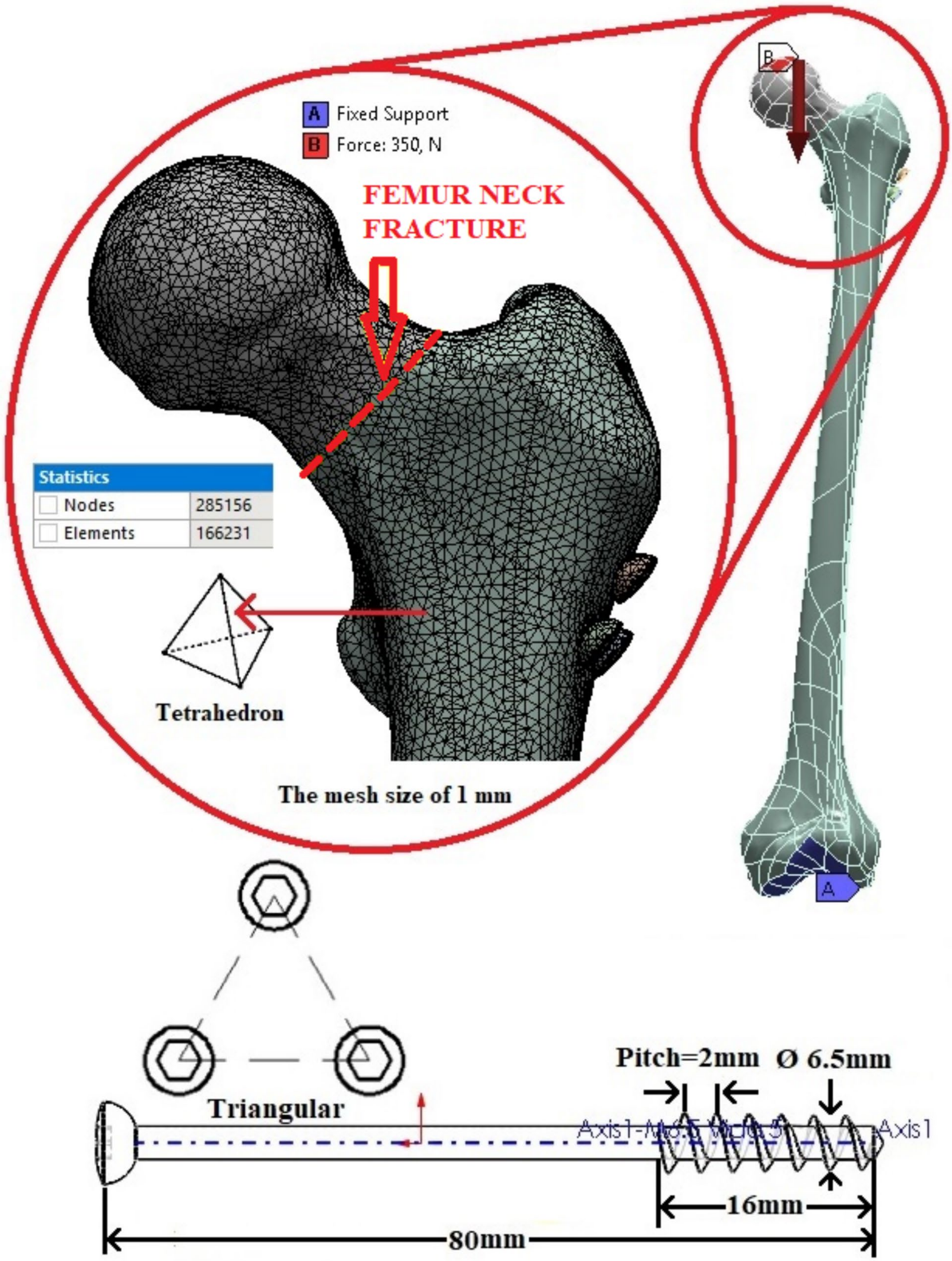


Fig. 1 The femoral neck fracture, screw and triangle configuration, boundary conditions

Fluent reports negative cell volumes if the mesh contains degenerate cells [19]. Skewness mesh metrics spectrum and orthogonal quality mesh metrics spectrum are given in Fig. 2.

In our analysis results, average skewness value was calculated as 0.43642 in Fig. 3. According to Fig. 2a, this value is very good (0.25–0.50). Average orthogonal quality value was also calculated as 0.98404 in Fig. 4. According to Fig. 2b, this value is excellent (0.95–1.00).

2.2 Material

In this study, linear isotropic material model was used to understand the biomechanical performance of PEEK as an alternative biomaterial. The mechanical properties are given in Table 1.

3 Results

In this study, the biomechanical performance of PEEK biomaterial for femur neck fractures was investigated and compared with the earlier studies Table 2. Figure 5a shows the stresses occurring at screws. Figure 5b also shows the deformations occurring at screws. It can be said that safety factor under loading of PEEK screws was calculated as 1.0297 as shown in Fig. 5c. The threshold value for this applications is generally accepted as 1–1.5. That's why,

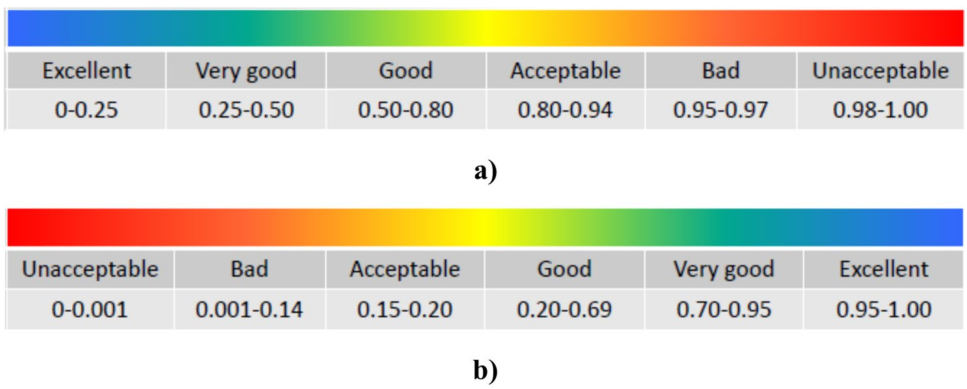


Fig. 2 The mesh metrics spectrum, **a** skewness, **b** orthogonal quality

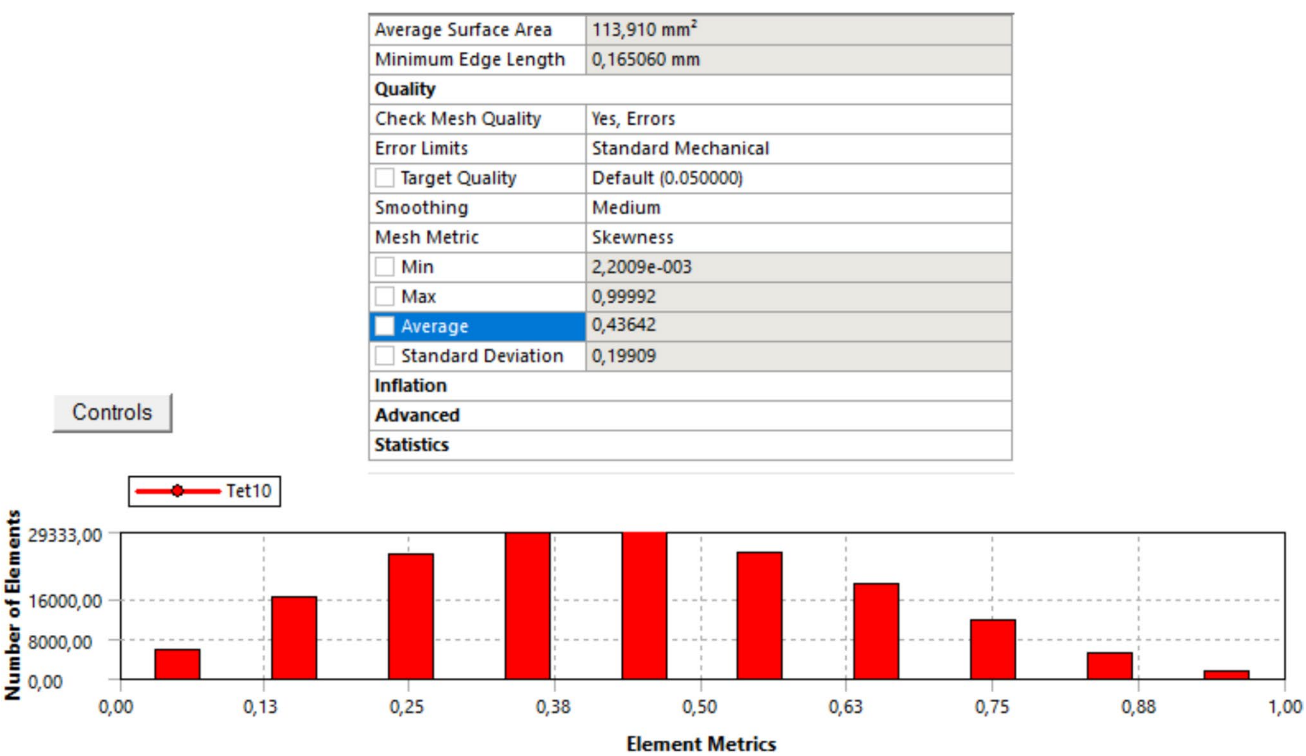


Fig. 3 Calculated average skewness value

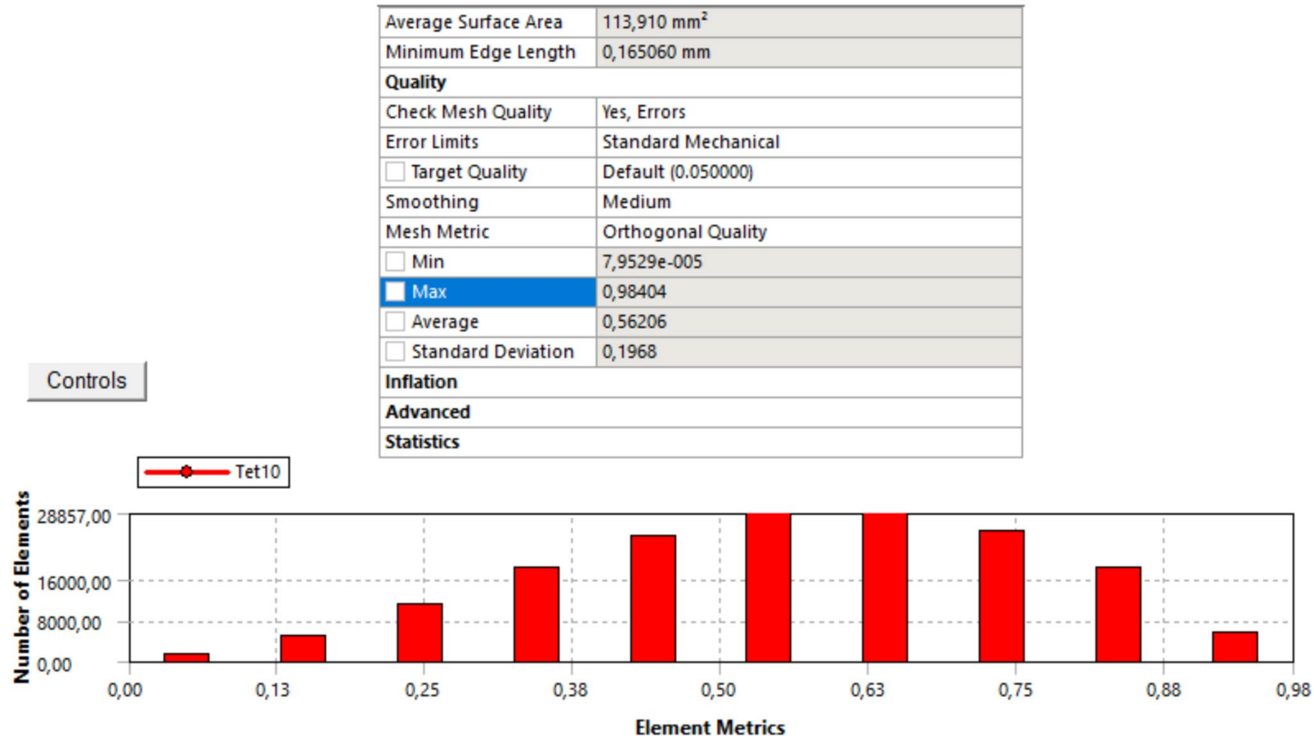


Fig. 4 Calculated average orthogonal quality value

Table 1 Mechanical properties for bone and screws used in FEA [20, 21]

Parameters	PEEK	Bone
Density (kg.m^{-3})	1310	2100
Elasticity modulus (GPa)	3.9	17
Tensile yield strength (MPa)		135
Tensile ultimate strength (MPa)	95	148
Poisson ratio	0.4	0.35

PEEK screws is safe for a standard individual, however this situation may lead to negative outcomes for a heavier individual.

The PEEK values obtained in Tables 2 are verified by the verification equations (Eq. 1–6) given in Appendix. This set of equations allows validation using parameters such as screw stress, fracture line stress, gap, penetration, and shear distance. It was determined that the values obtained as a result of the calculations made with the verification equation, and the values obtained from the numerical results were very close to each other.

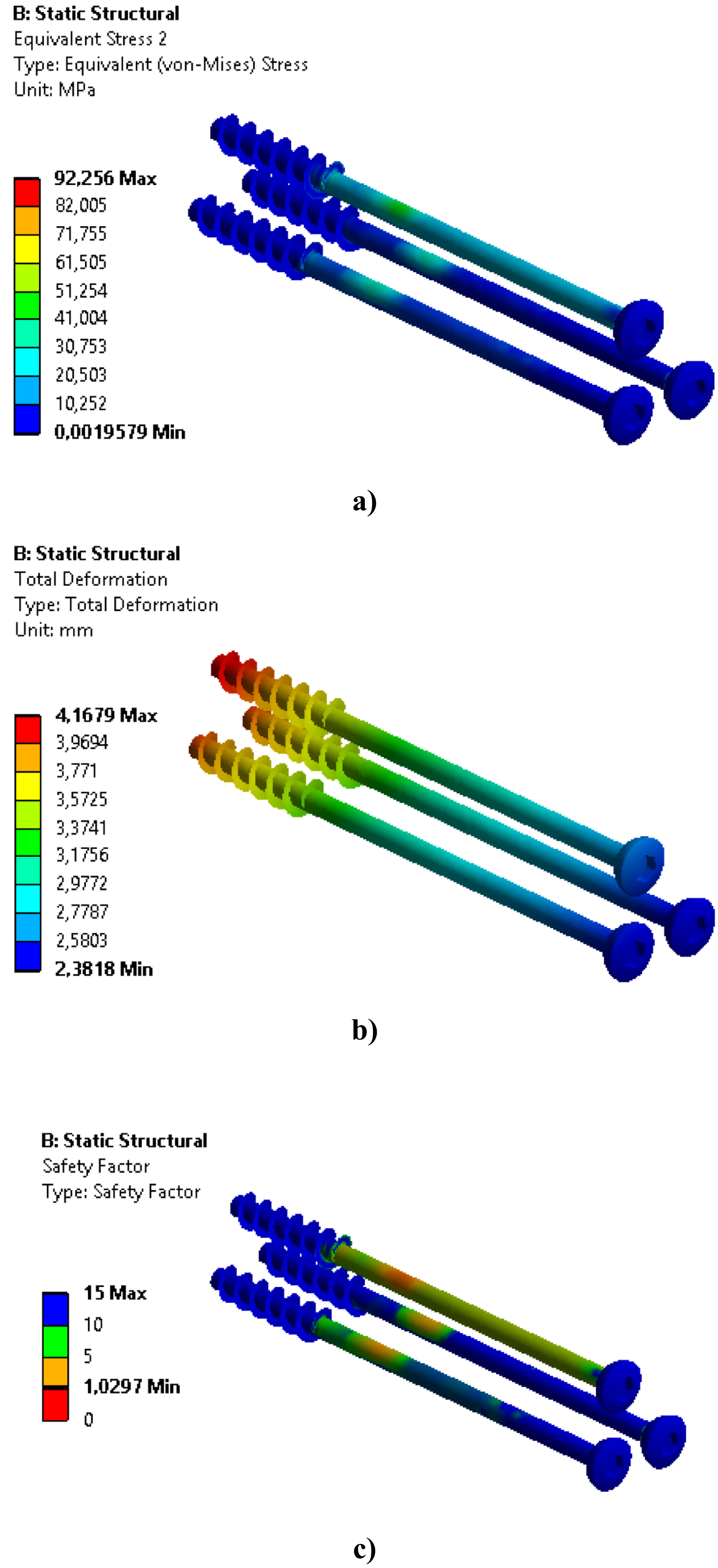
4 Discussion

Although the results and safety factor calculations presented in the table suggest that PEEK screws are a reasonable alternative for femoral neck fractures, certain mechanical

Table 2 Stress and deformation values in bones and screws

Screw material	Stress distributions					
	Screw stress (MPa)	Fracture line (MPa)-upper	Gap (mm)	Penetration (mm)	Sliding distance (mm)	Deformation values (mm)
PEEK	92.256	79.955	0.50158	0.007432	0.001273	4.1679
Ti6Al4V [22]	149.12	20.95	0.036672	0.0028687	0.00245	3.6329
AZ91 [22]	113.34	27.70	0.062408	0.0031284	0.0033489	3.6621
Ti6Al4V-HA [17]	148.56	20.87	0.036427	0.0028631	0.002439	3.6326
Ti6Al4V-hBN [17]	147.96	20.79	0.036196	0.0028579	0.0024300	3.6323

Fig. 5 PEEK screws, **a** the stress distribution, **b** the deformation distribution, c) the safety factor



limitations must be considered. The relatively low screwing stress of PEEK screws (92.256 MPa) helps mitigate the stress-shielding effect by distributing the load over a broader area. However, the elevated stress at the fracture line (79.955 MPa) may increase the mechanical burden on the bone. Furthermore, due to the lower rigidity of PEEK, the observed gap (0.50158 mm) and penetration (0.007432 mm) values are higher than those of titanium alloys, indicating a greater degree of micromotion at the bone–implant interface. The calculated safety factor of 1.0297 falls within the generally accepted threshold range of 1–1.5 in orthopaedic applications, suggesting adequate safety for standard patients but raising concerns regarding mechanical stability in cases of higher load-bearing demands.

To read in this study, although our implant demonstrates high strength, it exerts greater load on the fracture line compared to other implants. While these measurements may initially appear to indicate a mechanical disadvantage, the penetration and sliding values of our implant remain within safe limits. It is proposed that this increased load on the fracture line, in conjunction with the implant's controlled penetration and sliding characteristics, may induce low-to-moderate interfragmentary movement. This biomechanical condition could be advantageous in the early stages of fracture healing. Numerous studies have demonstrated that controlled loading and micromovement between fracture fragments during the early healing phase contribute to enhanced biomechanical stiffness, callus formation, and overall stability, surpassing the outcomes associated with absolute stability approaches [9]. Furthermore, the use of the implant may be contraindicated in patients with obesity, cognitive impairments, limited compliance, communication disorders, or balance deficiencies.

In this study, the 92.256 MPa stress observed in the PEEK screw exceeded the fracture line limit (79.955 MPa) indicating the limited load-carrying capacity of the material [8]. However, the 0.50158 mm gap is consistent with the literature supporting micromotion healing [10, 11]. While the low penetration (0.0074) and slip (0.00127 mm) values indicate that it maintains stability, the 4.1679 mm deformation reflects the flexible structure of PEEK. This deformation may require careful loading and monitoring in the postoperative period [12].

PEEK's excellent biocompatibility and advantages over metal materials offer significant development potential for orthopaedic implants. With additive manufacturing (3D printing) technologies, personalized PEEK implants can be produced quickly and provide solutions for rare or complex clinical cases [23, 24]. In addition, this technology enables the development of implants with superior mechanical performance compared to traditional production methods by creating a gradient in porous structure and material components [25].

5 Conclusion

PEEK screws present a promising alternative for femoral neck fracture fixation due to their low screwing stress (92.256 MPa) and biocompatibility. However, mechanical limitations, including high fracture line stress (79.955 MPa), increased micromotion (0.50158 mm gap, 0.007432 mm penetration), and a borderline safety factor (1.0297), raise concerns about their suitability for high-load patients. To ensure long-term clinical success, mechanical enhancements or surface modifications are essential.

It was stated that the implant examined in the study created a high load on the fracture line, but this load could support healing by providing controlled interfragmentary movement due to safe penetration and sliding values. It was supported by the literature that micromotions contribute to early fracture healing and accelerate healing by increasing corticomedullary blood flow. While the choice of PEEK material allows the load-bearing capacity to be gradually increased, it is emphasized that the implant requires regular clinical and radiological follow-up. However, it has been stated that it is not suitable for patients who are overweight or have mental or physical coordination problems.

This study highlights the potential of PEEK implants as a bioadaptive alternative to traditional metallic screws in orthopaedic applications. Unlike rigid implants that enforce absolute stability, PEEK's inherent flexibility supports controlled micromotion at the fracture site, which may enhance callus formation and promote early-stage healing. While its mechanical strength may not be ideal for all patient groups—particularly those with high-load demands the balance between stability and mobility it offers can be advantageous in standard cases. Moreover, the compatibility of PEEK with additive manufacturing enables the creation of personalized, structurally optimized implants, suggesting a promising direction for future orthopedic solutions focused on both mechanical performance and biological integration.

Author Contributions KG coordinated this research and drafted the manuscript. AG carried out numeric analysis. LU provided a literature review and revealed the differences with the study. CK formed the discussion and material and method sections of the study. SI prepared the Figures and Tables and helped discussion section.

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Declarations

Conflict of interest We have no conflict of interest.

Ethical Approval None.

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