Comparative Analysis of Conventional and Spring - Integrated Tibial Spacer Designs

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ABSTRACT

A conventional UHMWPE tibial spacer and a spring-integrated spacer manufactured were evaluated under compressive loading using FEA in ANSYS Workbench at 3.085 MPa. The conventional design showed a maximum von Mises stress of 9.91 MPa and deformation of 0.312 mm, while the spring-integrated design exhibited 862.66 MPa stress and 0.899 mm deformation. Although the spring design provides greater compliance and shock absorption, its high stress concentration indicates the need for further optimization. Overall, the conventional spacer demonstrated better structural stability.

KEYWORDS: Total Knee Arthroplasty; UHMWPE; Tibial Spacer

1. INTRODUCTION

Total Knee Arthroplasty (TKA) is widely used to restore knee function in patients with advanced knee disorders. The tibial spacer, commonly fabricated from Ultra-High Molecular Weight Polyethylene (UHMWPE), provides load bearing with low friction, biocompatibility, and wear resistance [1]. However, conventional UHMWPE spacers have limited compliance and shock absorption under high compressive loads. Therefore, a compliant spring integrated within the spacer is proposed to enhance deformation and load absorption. Finite Element Analysis (FEA) provides an effective tool for comparing stress and deformation behaviour during preliminary design [3]. This study compares conventional and spring-integrated spacers under identical compressive loading conditions [1-4].

2. MATERIALS AND METHODS

In SolidWorks 2 tibial spacer design was developed and analysed in ANSYS Workbench. The conventional UHMWPE spacer was designed into the case of Design 1. The following material properties of UHMWPE were used for modelling: Young's modulus of 758.4 MPa, Poisson's ratio of 0.42, density of 930 kg/m³, and tensile strength of 21.4 MPa [1]. Design 2 was the same UHMWPE spacer body with a built-in Ti-6Al-4V titanium alloy spring. The spring was taken to have a Young's modulus of 113.8Gpa, Poisson's ratio of 0.342, a density of 4430kg/m³ and a yield strength of 880MPa. The material data for the simulation is given in the uploaded research work. Using patch-conforming meshing a tetrahedral mesh was produced. The conventional model employed an element size of 3 mm, and the refined model employed an element size of about 0.5 mm. A pressure of 3.085 MPa was applied to the top surface, while the bottom surface was fixed, to simulate the condition of a body-load of 200 kg. Equivalent von Mises stress, total deformation, directional deformation, and equivalent elastic strain were obtained from the FEA as shown in Figure 1. [1,4]

3. RESULTS

As in Table 1, the von Mises stress, total deformation and the maximum equivalent elastic strain of the conventional UHMWPE spacer were 9.91 MPa, 0.312 mm and about 0.0108, respectively. The spring-integrated spacer exhibited significantly higher deformation of 0.899 mm, and hence a higher degree of compliance, but a maximum von Mises stress of 862.66 MPa and an equivalent elastic strain of 0.0343.

The traditional structure design therefore has significantly lower stress and higher structural stability. Although the spring concept was investigated due to the increased deformation, the high stress

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suggests that there may be significant stress concentration in the Ti-6Al-4V spring. The maximum stress is reported at approximately 880MPa, with the yield strength of the specified material being 880MPa, which means that the current geometry of the spring still needs to be optimised prior to mechanical suitability of the spring. [1,3]

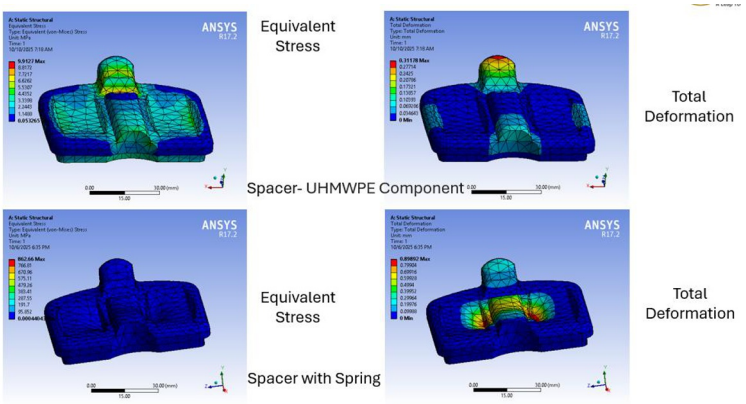


Figure 1. Equivalent von Mises stress and total deformation for (a) UHMWPE and (b) Spring-integrated spacer

Table 1. Comparison of FEA Results

Parameter	Regular UHMWPE Spacer	Spring-Integrated Spacer
Maximum von Mises Stress (MPa)	9.91	862.66
Total Deformation (mm)	0.31178	0.89892
Directional Deformation (mm)	0.04576	0.16562
Equivalent Elastic Strain	0.0108	0.0343

4. CONCLUSION

FEA results show that the conventional UHMWPE tibial spacer provides better structural stability, with lower von Mises stress (9.91 MPa) and deformation (0.312 mm). The spring-integrated spacer achieved greater deformation (0.899 mm), indicating improved compliance and potential shock absorption.

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