Computational Assessment of Stress Distribution and Fatigue Resistance for Optimal Orthopedic Hip Implant

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Abstract

The performance, lifespan, and biomechanical compatibility of orthopedic implants are significantly impacted by the materials chosen. CoCrMo, Ti-6Al-4V, and Ti-13Nb-13Zr alloys' fatigue resistance and stress distribution were examined using finite element analysis (FEA) in ANSYS 2024 R1. The mechanical properties of three distinct femoral stem geometries—straight, stepped, and conical—were evaluated under realistic loading scenarios. The route approach to stress analysis revealed that material qualities influenced the patterns of stress distribution, with medial stressors consistently showing higher values than lateral stresses. While fatigue life for Ti-13Nb-13Zr was calculated using Basquin's equation, fatigue analysis was carried out using the Stress-Life (S/N) methodology, sourcing Ti-6Al-4V and CoCrMo data from the body of existing literature. Out of all geometries, the results showed that Ti-13Nb-13Zr had the maximum fatigue resistance, followed by Ti-6Al-4V, while CoCrMo had the lowest fatigue safety factor. Furthermore, as compared to other geometries, straight stems continuously produced better fatigue performance. These findings offer important insights for improving the design and selection of orthopedic implants by highlighting the crucial roles that material selection and implant design play in affecting stress distribution and fatigue lifespan.

Keywords

Finite Element Analysis (FEA), Fatigue Resistance, Orthopedic Implants, Ti-13Nb-13Zr Alloy.