Finite Element Analysis of a Ti-6Al-4V Tibial Base Plate for Adaptive Manufacturing of Knee Implants

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ABSTRACT

Adaptive manufacturing integrates computational simulation with advanced manufacturing to optimize orthopedic implant design. A Ti-6Al-4V tibial plate was analyzed using ANSYS Mechanical 2025 R2 where a compressive load of 2000 N was applied on the model while restraining the bottom surface of the implant. Equivalent von Mises stress, total deformation, and equivalent elastic strain were evaluated. The simulation results showed a maximum equivalent stress of 1.835 MPa, maximum deformation of 1.352×10^{-7} m, and equivalent elastic strain of 1.661×10^{-5}. The implant remained within the elastic range, indicating satisfactory structural integrity.

KEYWORDS: Adaptive Manufacturing; Finite Element Analysis; Ti-6Al-4V; Knee Implant

1. INTRODUCTION

Total Knee Arthroplasty (TKA) is widely used to restore knee joint function in patients with severe knee disorders. Implant performance depends on material selection, mechanical properties, and structural durability. Ti-6Al-4V alloy is used in orthopaedic implants due to its biocompatibility, corrosion resistance, good strength-to-weight ratio and favourable mechanical properties [1,2]. Therefore, this study proposes an FEA-guided design-feedback approach for evaluating a Ti-6Al-4V tibial base plate within an adaptive manufacturing framework. The structural response under static compression is assessed using equivalent von Mises stress, total deformation, and equivalent elastic strain. The novelty of this work lies in integrating these FEA-derived responses as quantitative design-feedback parameters to support subsequent geometric modification and manufacturing decisions for Ti-6Al-4V tibial base plates.

2. MATERIALS AND METHODS

The Ti-6Al-4V three-dimensional base plate model of the tibia was created and analysed via ANSYS Mechanical 2025 R2 under the effects of static loads. Ti-6Al-4V was selected because of its biocompatibility, corrosion resistance and strength-to-weight ratio [2,3]. FEA was used as a pre-fabrication design-feedback step within the adaptive manufacturing cycle, with stress, deformation, and strain serving as structural performance indicators [4].

3. RESULTS

Static structural analysis was performed under a 2000 N load. The maximum equivalent stress, total deformation, and equivalent elastic strain were 1.835 MPa, 1.352×10^{-7} m, and 1.661×10^{-5}, respectively. Stress concentration occurred near the constrained and loading regions as seen in Figure 1.

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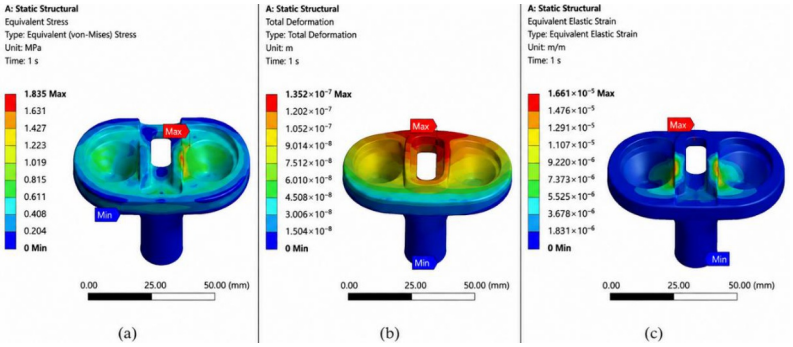


Figure 1. FEA results showing (a) stress, (b) deformation, and (c) elastic strain.

Table 1. Summary of FEA results

Parameter	Unit	Value
Applied Load	N	2000
Maximum Equivalent (von Mises) Stress	MPa	1.835
Maximum Total Deformation	m	1.352×10^{-7}
Maximum Equivalent Elastic Strain	m/m	1.661×10^{-5}

4. DISCUSSION

The maximum equivalent stress of 1.835 MPa remained below the reported yield strength of Ti-6Al-4V (Table 1), indicating elastic behaviour under the applied load [2]. The low deformation and elastic strain indicate structural stability. The proposed workflow uses these FEA outputs as pre-fabrication design feedback to identify critical regions and guide subsequent geometric or manufacturing modifications.

5. CONCLUSION

FEA demonstrated satisfactory structural behaviour of the Ti-6Al-4V tibial base plate under a 2000 N compressive load. The proposed simulation-based workflow provides design feedback for subsequent implant modification and adaptive manufacturing. Experimental and fatigue validation are required in future work.

REFERENCES

[1] M. Geetha, A. K. Singh, R. Asokamani, and A. K. Gogia, "Ti based biomaterials, the ultimate choice for orthopaedic implants—A review," *Progress in Materials Science*, vol. 54, no. 3, pp. 397–425, 2009. https://doi.org/10.1016/j.pmatsci.2008.06.004

[2] M. Niinomi, "Mechanical properties of biomedical titanium alloys," *Materials Science and Engineering: A*, vol. 243, nos. 1–2, pp. 231–236, 1998. https://doi.org/10.1016/S0921-5093(97)00806-X

[3] K. P. Iyengar, N. R. Garg, A. K. Jain, *et al*., "Smart sensor implant technology in total knee arthroplasty," *Journal of Clinical Orthopaedics and Trauma*, vol. 18, pp. 125–131, 2021. https://doi.org/10.1016/j.jcot.2021.04.017

[4] J. Wang, Y. Zhang, X. Liu, *et al*., "The application of implantable sensors in the musculoskeletal system: A review," *Frontiers in Bioengineering and Biotechnology*, vol. 12, Article 1360844, 2024. https://doi.org/10.3389/fbioe.2024.1360844

[5] E. Kelmers, A. Szuba, S. W. King, *et al*., "Smart Knee Implants: An Overview of Current Technologies and Future Possibilities," *Indian Journal of Orthopaedics*, vol. 57, pp. 635–642, 2023. https://doi.org/10.1007/s43465-022-00810-5

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