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*Abstract*

# A biomechanical testing framework for additively manufactured trauma implants by replicating fractures under multiaxial loading

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Bone fractures represent a significant global health burden, with a standardised incidence rate of 187.2 per 100,000 population (2019), specifically hip fractures are affecting around 14.43 million people per year globally [1]. Femoral fractures are associated with morbidity, mortality, and socioeconomic cost. Additive manufacturing (AM) offers clinical potential in orthopaedic fracture management, providing design variability, tunable mechanical properties, and fabrication of biocompatible implants [2]. However, this requires understanding fracture morphology under realistic, multiaxial loading conditions. Existing biomechanical studies have not addressed this gap, due to their uniaxial or indirect combined loading test setups [3]. CT-based finite element analysis with experimental validation, has demonstrated accuracy in predicting fracture location.

This study proposes a framework for integrating CT-based finite element modelling, multiaxial robotic fracture testing, and additive manufacturing. With the aim of producing AM trauma implants from the biomechanical testing conducted under controlled multiaxial loading conditions. The need arises from increasing use of additively manufactured patient specific implants that ideally must be tested preclinically under realistic conditions.

Specimen-specific finite element models will be developed from CT-scanned cadaveric specimens with density-mapped material properties. Multi-axial loading conditions will be implemented to identify the stress concentration regions, and these conditions will be translated into a multiaxial robotic testing platform (SimVITRO) for physically reproducing the fracture type in a controlled manner. Each of the fractures will be classified according to the AO/OTA Classification.

The data is expected to serve as a basis for understanding fracture morphology, geometric parameters and anatomical location. The multi-axial load data can be used to design 3D-printed topology optimized biocompatible trauma implants. Designed with custom architectures and engineered to match local bone stiffness and promote fracture union. This framework aims to generate an AM implant design indexed to AO fracture classification, enabling surgeons to match implants to fracture types during clinical decision-making.

**AUTHOR'S STATEMENT**

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**REFERENCES**

[1] M. H. Razzaq, M. U. Zaheer, H. Asghar, O. Cenk Aktas, Mehmet Fatih Aycan, and Y. K. Mishra, "Additive manufacturing for biomedical bone implants: Shaping the future of bones," *Materials Science and Engineering R Reports*, vol. 163, pp. 100931–100931, Jan. 2025, doi: https://doi.org/10.1016/j.mser.2025.100931.

[2] Y. Rau, J. Amtsfeld, N. Reimers, Ludwig Matrisch, J. Frese, and A.-P. Schulz, "The development, incidence and treatment trends of trochanteric fractures in Germany: a cohort study," vol. 18, no. 1, Jul. 2023, doi: https://doi.org/10.1186/s13018-023-03981-5.

[3] A. C. Courtney, E. F. Wachtel, E. R. Myers, and W. C. Hayes, "Effects of loading rate on strength of the proximal femur," *Calcified Tissue International*, vol. 55, no. 1, pp. 53–58, Jul. 1994, doi: https://doi.org/10.1007/BF00310169.

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