IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 2 June 2024, accepted 24 June 2024, date of publication 28 June 2024, date of current version 10 July 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3420756

RESEARCH ARTICLE

Subdivision Strategies for Bone Models: A Comprehensive Analysis of Geometric and Visual Quality

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This work has been supported by the Ministerio de Economía y Competitividad and the European Union (through FEDER funds) through research project DPI2015-65123-R. Open access funding: University of Jaén.

ABSTRACT Bone fracture modeling is a major challenge in medical image analysis and simulation, requiring accurate strategies to faithfully represent complex fracture patterns. This study conducts a comprehensive analysis of three subdivision strategies: approximation, triangulation, and a hybrid approach. The approximation method preserves mesh topology but exhibits visual inconsistencies with non-horizontal fractures. Triangulation accurately represents fractures but alters mesh topology. The hybrid approach balances geometric accuracy and visual fidelity by dynamically adjusting an approximation threshold. This minimizes deviations from the original fracture pattern and maintains visual quality. Using quality metrics, we evaluate these strategies for geometric accuracy, visual fidelity, and mesh topology. Our results indicate that the hybrid approach effectively balances accuracy and visual quality, making it a promising solution for bone fracture modeling. Expert validation and quantitative metrics underscore the importance of tailored approaches for different fracture patterns. This study significantly advances computational models for clinical and research applications, offering enhanced tools for improving the accuracy and realism of bone fracture simulations, ultimately benefiting surgical planning, prosthetic design, and medical training.

INDEX TERMS Bone fracture modeling, fracture pattern representation, geometric quality assessment, mesh subdivision strategies, quality metrics, triangulation techniques, visual realism.

I. INTRODUCTION

The research and practical application of bone models extend across diverse fields, including education, research, surgical planning, and medical device design [1]. In the biomedical and clinical field, bone models play a crucial role in various applications [2]. For research and education, they provide valuable resources for studying and teaching the anatomy, physiology, and biomechanics of bones [3]. They serve as effective visual learning tools, allowing for in-depth exploration of the skeletal system.

In surgical planning, bone models offer precise physical replicas of areas of interest, facilitating meticulous preoperative planning, enhancing surgical precision, and potentially reducing operation time and postoperative complications [4]. In medical device design and testing, such as for prosthetics and orthotics, bone models enable engineers to test functionality and durability in simulated environments that mimic the biomechanical properties of the human skeleton.

Bone models are also fundamental in biomechanical research, allowing for the simulation of mechanical loads, investigation of bone tissue properties, and examination of various skeletal disorders and injuries [5], [6]. The importance of bone models continues to grow, driven by advancements in modeling techniques, simulations, and applications [7], [8], [9]. High-fidelity and personalized digital bone models have significantly improved surgical planning,

The associate editor coordinating the review of this manuscript and approving it for publication was Roberta Palmeri.

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Dr. Jiménez-Delgado was a member of the Eurographics Association.

Open Access funding provided by 'University of Jaén' within the CRUI CARE Agreement