A COMPREHENSIVE SIMULATION-BASED METHODOLOGY FOR THE DESIGN AND OPTIMIZATION OF ORTHOPAEDIC INTERNAL FIXATION IMPLANTS

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ABSTRACT

Internal fixation implants are widely used by orthopaedic surgeons to stabilize various types of fractures in injured patients. However, the irregular geometry of the human skeletal system, as well as the significant variation in the size and shape of bones among the population, pose great challenges in efficiently and effectively designing such devices. As a result, the need for improvement in regard to performance and fit is evident in many current internal fixation implants, particularly for high load-bearing regions such as the femur. For this reason, a comprehensive methodology was developed to design and optimize implants with maximal structural integrity and contour fitting among the population, while minimizing its influence on human biomechanics. The systematic methodology uniquely employs both new and existing techniques in medical imaging analysis, non-linear finite element methods, and optimization to obtain optimal designs prior to experimental testing. Its efficacy was demonstrated using two case studies involving the design of internal fixation implants used to stabilize various femoral shaft fractures: intramedullary nailing and locking plate systems. Comparison of finite element results – from simulated physiological loading conditions and loads induced by "virtual surgery" – among the optimized implants and those currently used in the operating room showed much improvement in regard to reliability, fit, and alteration of natural biomechanics. Subsequent experimental testing verified that the results predicted by the developed simulation-based methodology represented actual physiological scenarios within acceptable percent error and were valid for design purposes.