

INFLUENCE OF TRABECULAR BONE DENSITY ON CALCANEUS FRACTURE IN AXIAL IMPACTS

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ABSTRACT

Calcaneus fractures can be caused by axial leg loading from falls, collisions, and underbody blast events. These injuries are difficult to treat and often result in long-term disability. Fourteen axial plate impacts (5.0 to 6.1 kg) at 10 or 15 m/s were collected for reference and validation to improve a finite element model. An LS-DYNA model of a 5.7 kg lower leg axial impact at 10, 15, and 20 m/s was updated with stress-based cortical bone and strain-based trabecular bone failure limits to capture fracture. The simulations and experiments were similar in peak force at 10 m/s (7.5 vs 7.9 kN respectively) and 15 m/s (13.4 vs 11.8 kN respectively) and the prediction of fracture at 15 m/s and higher. A quantitative CT study of 52 elderly legs defined the anterior and posterior trabecular densities. These new properties were incorporated into the finite element model, which slightly lowered peak force and localized damage to the anterior segment. These initial results show that the material properties and localized variations of the calcaneus trabecular bone can influence the resulting fracture. More work is needed to more accurately capture the local microstructure, individual variations, and address computational challenges introduced by the erosion models.

Keywords: Calcaneus, lower leg, biomechanics, fracture, finite element, bone mineral density, simulation, element erosion

INTRODUCTION

Calcaneus fractures are attributed to high energy axial loading of the leg. Falls and automotive collisions are the most common injury sources in the civilian population [1][2] whereas injuries in the military environment were 89% attributed to vehicle floor loading from improvised explosive devices [3]. Calcaneus fractures can be difficult to treat (75% are intra-articular) and reduction or surgical reconstruction is often performed when the surrounding soft tissue and bones are not damaged [4]. Treatment is typically followed by up to 8 weeks of non-weight bearing recovery.

While calcaneus fractures are ranked low on threat-to-life scales, these injuries can result in long-term chronic pain and disability. For the general population, calcaneus injuries are associated with a 20% functionality loss after 15 years induced by both lingering pain and reduced range of motion [4]. On the military side only 20% were medically fit to return to duty due to the higher physical demands, with disability attributed to pain, reduced joint mobility, and post-traumatic stress disorder [3]. Thus, there is a strong incentive to reduce the frequency and severity of calcaneus injuries because the disability costs remain high.

Finite element analysis can be used to understand how calcaneus fractures occur so that future injuries can be prevented. The calcaneus is often simplified into two component layers (trabecular and cortical bone) to reduce complexity, and each layer assigned a homogenous material definition. This study started with such a model and focused on improving the calcaneus by adding material failure model and local variations in the trabecular bone density, with the overall goal of enabling accurate prediction of calcaneus fractures.