H40 Numerical Simulation of Fracture Propagation in a Test of Cantilevered Tubular Bone

John F. Berryman, University of Tennessee, Lebanon, TN; Hugh E. Berryman, PhD, Metropolitan and Davidson County Medical Examiner's Office, Lebanon, TN; Robert A. LeMaster, PhD, PE, Department of Engineering, College of Engineering and Natural Science, Martin, TN; and Carrie Anne Berryman, MA, Vanderbilt University, Nashville, TN*

The objective of this paper is to present a new method for computing the geometry of fracture surfaces of bone.

Anthropologists recognize and use the fact that tubular bone fractures in a predictable way when cantilevered. Fracture orientation and surface morphology provides a means of establishing the mechanics involved in its production. The fracture typically propagates toward the cantilevered end, and a breakaway spur forms on the compression side of the cantilevered end. Although this pattern is recognized, the physics responsible for its production has never been demonstrated. A clear understanding of the physics involved in simple fracture production, as presented here, is an essential first-step toward the understanding of the factors affecting the formation of more complex fractures in tubular as well as flat bone.

This paper discusses the application of engineering fracture mechanics to the analysis of fracture formation in tubular bone specimens. The immediate objective is to present a new approach for the study of bone fracture—the Element-Free-Galerkin method coupled with a J-integral based crack propagation criteria. The Element-Free-Galerkin method was first introduced ca. 1994 by Belytschko, et al. The method is based on a generalization of the finite element method commonly used to compute the stress and deformation states in mechanical and human skeletal systems. The numerical method is general in scope and can be applied in principle to other bone morphologies.

In 1995, Belytschko applied the Element-Free-Galerkin method to the analysis of two-dimensional static and dynamic fracture problems. All of the problems considered by Belytschko used linear elastic fracture mechanics theory and concerned crack propagation in flat plates. It was shown that the Element-Free-Galerkin method was uniquely suited to crack propagation calculations because it is not necessary to regenerate the computational mesh as the crack propagates. Methods that require the regeneration of the computational meshes are computationally intensive, inherently slow, and often require user interaction. This first application of the Element-Free-Galerkin method to crack propagation was limited to linear materials that are brittle in nature and experience only small amounts of "blunting" (i.e., permanent deformation) at the crack tip. Cast iron is an example of an engineering material that demonstrates these properties.

In this study, the Element-Free-Galerkin method is extended to the fracture of tubular bone. A non-linear fracture mechanics approach, based on the J-integral fracture parameter, is used to control the crack growth rate and propagation direction. The J-integral was initially developed for elastic-plastic materials, but has been shown to work well with other nonlinear materials. The ultimate goal of this research is to develop a computer program that can compute fracture surface geometry based on bone morphology and loading data. For this study, the fracture morphology commonly seen in the fracture of cantilevered tubular bone (i.e., an angled fracture with a breakaway spur) is compared to simulation results. Areas in which the simulation results agree/disagree with the experimental data are discussed. The results of this study contribute significantly to the understanding of how engineering fracture mechanics theories and computational methods can be used to explain specific fractures. Eventually, virtual models of various bones in three-dimension may be used to facilitate an understanding of the mechanics involved in the production of butterfly, spiral and other fractures commonly seen in tubular bone. In addition, the affects of the cross-sectional shape of bone (e.g., femur versus tibia) and bone buttressing on fracture morphology may be examined with this approach. This approach will also allow the investigation of varying intrinsic qualities (e.g., bone brittleness and elasticity), as well as extrinsic factors (e.g., rate of loading, area of application, and impulse).

Although the methods used in this study are highly mathematical and use advanced simulation methods, the purpose of this paper is to provide the forensic community with an overview of a new simulation method and the results of a research study without dwelling on the mathematical detail. Computer generated images and graphs will enable the results to be understood.

Bone Trauma, Finite Elements, Fracture Mechanics

 ** Presenting Author*