Three-dimensional finite element models of a human tibial fracture

V. Vijayakumar¹, L. Marks², S. Mishra¹, E. Loveday³, A. Bremmer-Smith³, J. Hardy³, and T.N. Gardner¹
¹Oxford Orthopaedic Engineering Centre, University of Oxford, U.K.
²Integrated Analysis Solutions, Whitney, U.K.
³Avon Orthopaedic Centre, Bristol, U.K.

Introduction:

It is universally accepted that the mechanical environment plays a significant role in the process of fracture healing. It has been shown that cyclical interfragmentary motion (IFM) can induce callus formation, and that both insufficient and excessive movement results in callus of low mineral density. As the mechanism by which the mechanical environment influences the callus is poorly understood, there is considerable interest in this area of research.

Complete stress analysis of bone and callus is possible only through the use of three-dimensional finite element (FE) analysis, as this is currently the only method that can represent the inherent geometrical and material complexities of a real fracture. In the past, such modelling has been limited to either highly idealised 3D geometry, or to representative 2D models. This has been due primarily to the difficulty associated with generating accurate 3D models by conventional methods. Additionally, it has been due to the difficulty in obtaining accurate in-vivo data, as previous FE studies have largely used arbitrary values for loads, IFM, and material properties.

Methods:

Subjects with non-comminuted mid-shaft tibia fractures, stabilised using commercially available external fixtures in standard configuration, are seen at approximately 4-week intervals post-operation until fixture removal. A Vicon, 7-camera optimetric system is used for motion analysis, in conjunction with a lower limb biomechanics model that is customised to the subject. Force plate and electromyographic data are measured during isometric and walking tests. IFM is recorded simultaneously using an instrumented micromovement transducer capable of measuring movement in six degrees of freedom.

At the same intervals, CT scans of the fractured limb are taken and are processed using a semi-automated computer based system to generate exact 3D models of the subject’s callus and bone. Tissue regions are defined using a thresholding histogram function, and average pixel intensity is determined for each region of the callus. The resulting model is then exported to the FE solver for meshing and analysis (figures 1:3).

Discussion:

The method developed addresses the major sources of error in the modelling of fracture healing. Both the geometry and the loading conditions can be accurately defined. Further the callus material properties can be modified iteratively until good agreement is found between the calculated resultant force from the lower limb biomechanics model and the resultant force generated by the FE solution. The pending analysis is expected to yield valuable information concerning the role of the mechanical environment in tibial fracture healing.
Figure 1: 3D finite element model of fractured tibia at 7 weeks post-injury

Figure 2: 3D finite element model of fractured tibia at 10 weeks post-injury
Figure 3: 3D finite element model of fractured tibia at 16 weeks post-injury