INTRODUCTION

This study investigates an improved finite element (FE) mesh for long bone fracture risk analysis. Osteogenesis imperfecta (OI) is a heritable bone fragility disorder with several clinical types (I-VIII) which are characterized by skeletal deformity and “brittle” bones. It is estimated that the disorder affects 20,000 to 50,000 persons in the United States (1). OI bones exhibit abnormal mineralization and altered mechanical properties of bone tissue. Across all types, the poor bone quality poses major orthopaedic and rehabilitation challenges. Fractures in OI patients result from numerous factors, including altered bone material properties and geometry as well as loading on the bone. Risk of fracture is a major consideration when prescribing activity restrictions and physical therapy. Quantifying bone fracture risk would be an invaluable clinical tool for treating children with OI. FE models have the potential to provide patient-specific feedback on the effects of fracture risk factors in long bones, such as the femur and humerus. A patient-specific FE model of an OI type I patient’s femur during normal ambulation has been developed and assessed for fracture risk (2). This model was automeshed using tetrahedral elements in Abaqus. Although tetrahedral elements may be readily used to mesh virtually any structure, their behavior tends to be overly stiff. Consequently, hexahedral elements are often preferable. To improve the biofidelity of the fracture risk assessment model, a new all hexahedral mesh was developed using IA-FEMesh (3). The new model comprised a parametric study of the effects of lateral bowing, which included the level of bowing modeled in the original patient-specific FE analysis (Fig. 1).

METHODS

The current model was meshed in IA-FEMesh and analyzed with Abaqus (3). The femur geometry originated from a surface file of a reconstructed CT scan of an adult femur. Using IA-FEMesh, the femur was meshed with an outer cortical shell, inner cancellous layer and an intermedullary canal. Based on material property data from literature, the cortical and cancellous layers were assigned Young’s modulus values of 17 GPa and 15 GPa, respectively (4). Once the mesh was generated, it was scaled to match that of the original tetrahedral mesh. To introduce the bowing as illustrated in the coronal plane x-ray (Fig. 1) we relied on an FE displacement analysis. Displacements were applied to a set of nodes corresponding to the apex of bowing and the model was run in Abaqus. The coordinates resulting from the applied displacement were calculated and assigned as the coordinates for the new ‘bowed’ mesh. Figure 2 shows how the loads from the kinetic results of gait and muscle forces were applied to the model (2). The full analytical set consisted of a series of seven models; one without...
bowing, a second with 5 mm of lateral bowing and five more models where the bowing was incrementally increased by 10 mm. The FE model was run and analyzed for maximum von Mises stresses.

![Figure 2. FE model of bowed femur (15 mm).](image)

**RESULTS AND DISCUSSION**

As expected, the results show that the maximum von Misses stress values increase with the level of bowing. Interestingly, it exhibits a linear relationship (Fig. 3).

![Figure 3. Scatter plot of von Mises stress results.](image)

The original model with a tetrahedral mesh exhibited a maximum von Mises stress around 30 MPa for the same loading condition with lateral bowing of 7 mm. The maximum von Mises stress of the model with hexahedral elements is over 50% higher than that of the tetrahedral mesh. This indicates that the tetrahedral elements create a stiffer model than the hexahedral elements. However, the current model also had a cancellous layer, whereas the original model had a single material with a Young’s modulus of 17 GPa. This would account for a portion of the difference in stress levels seen with the same loading conditions.

The all hexahedral mesh resulted in a smoother geometry and mesh for the FE model. It allowed for smooth meshing of complex geometry. Since the model’s ultimate goal is to examine femoral fracture risk in patients with OI, having a good mesh is essential to represent the complex and often abnormal geometry of OI femurs. The next step for the fracture risk assessment model is to examine the sensitivity to applied muscle forces and compare those results to the original model (4). Concurrently, studies are being conducted to better characterize the structure of OI bones, which is another contributing factor to fracture risk (6). The overall aim is to create and implement a method for patient-specific FE model to assess fracture risk and predict potential femoral fracture for persons with OI.

**REFERENCES**


**ACKNOWLEDGEMENTS**

The contents of this abstract were developed under a grant from the Department of Education, NIDRR grant number H133E100007. However, the contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government. We would also like to thank the MIMX lab members at The University of Iowa for IA-FEMesh training.