PARAMETRIC FINITE ELEMENT MODEL OF FEMUR FROM CT DATA

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INTRODUCTION

The investigation of the individual effects of structural and geometrical parameters on the bone strength can lead to a better understanding of the mechanisms and risk factors associated with a range of bone problems including fracture, aging, osteoporosis, and bone loss in microgravity. A semi-automatic technique is used to develop a finite element model of the femur bone from the CT data. The major difference between this technique and other FE models of the femur is that it is based on the parameterization of the bone; therefore, it directly lends itself to a sensitivity analysis of the femur's structural and geometrical factors. This work is the extension to the elliptical model reported previously [1], and generates a more accurate geometry.

METHODS

A proximal femur of an average male cadaver was scanned using a CT scanner. The steps towards developing FE mesh were as follows: 1) Semi-automatic custom algorithms were applied to extract the bone's outer contours and density information from the CT data; 2) A piecewise continuous cubic spline fit was applied to parametrize the outer contours; 3) The inner contours were calculated such that the constraint equations for cross-sectional mass and moment of inertia along femoral shaft and neck axes were satisfied; 4) Scaling was performed on the regions of interest; 5) An automated algorithm generated the volumetric model including outline of the bone and the inner cortex boundaries. 5) The bone volume was meshed automatically with 20-node brick elements, as needed for finite element simulations.

Semi-automatic custom algorithms were applied to extract the bone's outer contours and density information from the CT data. The algorithm re-sliced images along the axis of the shaft and neck of the femur (the transition from shaft axis to neck axis was defined by a hyperbolic fit). Edge extractions were performed for the outer boundaries of the femur using the re-sliced sections along the femur's neck and shaft axes [2].

The algorithm performed a piecewise continuous cubic spline fit on the new reformatted slices along shaft and neck axis. A minimum number of control points that would adequately approximate the true geometry were found for each cross-section. The cross-sections were also visually inspected for the any potential imperfection.

The main challenge in creating accurate parametric bone geometry is the extraction of the contours of the inner cortex. We derived a theoretical and algorithmic technique for analytical calculation of the inner contour from the outer cortical boundary geometry. These calculations satisfy the mechanical properties of each cross section of the bone while producing a comparable geometry to the original bone. We

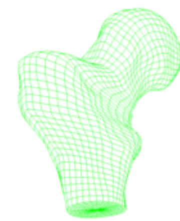

Figure 2: A finite element mesh of a proximal femur with neck-shaft angle reduced by 15^{o}

calculated the cortical/cancellous and cortical/marrow boundary such that the cross-sectional moment of inertia (CSMI) and cross-sectional area (CSA) of the model and the original bone remained equal (note that both are calculated from the mass of the cross-section based on one voxel thickness). We used the density map data for each cross-section plus the CSMI and CSA equations to calculate the appropriate spline fit to the cortical/cancellous or cortical/marrow boundaries. This enabled us to define the bone geometry and its material distribution with a finite number of control points for each cross-section. Thus, a full parametric model of the femur was created.

The regions of interest (e.g. neck angle, neck length) and cortical thickness was scaled using the cross-sectional geometries. An automated algorithm was developed to create surfaces on these cross-sections and mesh the generated volumes with 20-node hexahedral elements.

A TYPICAL EXAMPLE

The simulations were performed using SDRC-IDEAS finite element software. A typical example of the scaled bone is shown in Figure 1. The neck-shaft angle in this model was reduced by 15^{o} from the original CT data. The model had approximately 12000 hexahedral elements. Both cortical and cancellous layers had quality elements with maximum distortion less than 30%. In summary, the model from CT data included more accurate geometry than the previously reported elliptical model [1]. Additional user interaction, however, was required to verify the quality of the spline fits.

REFERENCES

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