A Novel High-Order Element for the Analysis of Heart Valve Leaflet Tissue Mechanics

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INTRODUCTION

Modeling heart valve leaflet tissue is challenging because the degree of anisotropy changes from one layer to the next due to changes in collagen fiber density and orientation. Also constitutive models describing the mechanical properties of the leaflet structure are not available. Here, we develop a high-order, single element to approximate the material properties of the heart valve leaflet tissue. This element accounts for the nonlinearity in leaflet properties using a bilinear material model, it is composed of a two-dimensional FE in the principal directions, and a p-type FE in the direction of thickness. The element is easy to implement, and is efficient and quick compared to commercially available elements.

METHODS

The heart valve leaflet was modeled using 183 high-order elements (Fig. 1A). The schematic 3D structure of the element is shown in Fig. 1B. It consists of 21 nodes with nonlinear boundaries. Each element has 55 degrees of freedom: 15, 15, and 25 in each of the principal displacement directions (ζ, η and z, respectively) at each node as shown in Fig. 3.

RESULTS

Fig. 2 shows the maximum principal stresses over two layers applied on a single leaflet tissue. The principal stresses differ between the top and bottom layer. The maxima of the first principal stress in the top and bottom layer are 580 kPa and 602 kPa, respectively. The maximum principal stress is located below the corners where the leaflet attaches to the stent (Fig. 2A) [1].

DISCUSSION AND CONCLUSIONS

A new high-order element with anisotropic and bilinear properties was developed to analyze a natural aortic heart valve. The element is less complex and faster than equivalent nonlinear finite elements. The model makes similar predictions as FEM solutions but results are obtained in a fraction of the CPU time.

REFERENCES


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