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AUTOMATIC DETECTION OF VERTEBRAL ENDPLATES

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SUMMARY

Detection and reconstruction of intervertebral discs from patient-specific vertebra isosurfaces is a well known problem as detailed geometric information is needed to predict the biomechanical behavior of the spinal motion segment. However, this task commonly involves manual identification of the endplates by means of landmark placement, resulting in tedious, time consuming work and results affected by intra- and inter-individual variability. Numerical methods permit an intuitive understanding of complex physical phenomena and have the advantage of being able to model very complex geometries and boundary conditions. Thus, the purpose of the present study was to develop an algorithm for automatic detection and reconstruction of intervertebral discs from patient-specific vertebra isosurfaces.

INTRODUCTION

The spine flexibility is an important biomechanical parameter in preoperative planning and surgical treatment of scoliosis. Clinically, the spine flexibility is assessed by different clinical tests such as supine or standing side-bending, fulcrum bending, push-prone, and traction films.

Recently, a study conducted by M. Robitaille et al. (2007) [1] involving a considerable group of experts in spine deformities has shown a high variability of preoperative planning. This result can be explained by considering that the human spine is an extremely complex 3D biomechanical structure with many degrees of freedom surrounded by numerous muscles. Moreover, it is characterized by a high number of tendons and ligaments. Furthermore, the spine is constituted by passive and active anisotropic properties and exhibits complex boundary conditions and geometry. Another important aspect regarding clinical tests for spine flexibility assessment is that the current tests measure mobility rather than mechanical properties, since the magnitude and direction of the forces are unknown and involve complex transmission mechanisms.

The characterization of the patient-specific spine mechanical properties and geometry are decisive factors in surgical intervention for scoliosis. Biomechanical models to simulate scoliotic spine surgical instrumentations and maneuvers were developed based on finite element and multi-body models [2,3]. The Finite element method permits an intuitive understanding of complex physical phenomena and has the advantage of being able to model very complex geometries and boundary conditions. Detailed geometric information is needed to predict the biomechanical behavior of the spinal motion segment [3]. However, the manual identification of the endplates by means of placement of landmarks can be tedious, time consuming and intra-and inter-individual variability of endplate geometries must be considered. Consequently, the purpose of the present study was to develop an algorithm for automatic detection and reconstruction of intervertebral discs from patient-specific vertebra isosurfaces.

METHODS

An illustration of the proposed algorithm is outlined in Figure 1. The technique was evaluated on CT scan data of an individual with congenital scoliosis. Firstly, lumbar vertebrae were segmented and their respective isosurfaces were extracted based on the marching cubes algorithm [4] as shown in Figures 1A and 1B, respectively. Secondly, principal components analysis was applied to the 3D points coordinates of each individual vertebra and transformed into the space defined by the eigenvectors of the covariance of the data, i.e., principal component space as shown in Figure 1C. Thirdly, unit normal vectors were computed for all elements of the mesh in the principal component space (Figure 1E) and a threshold based on the component of the unit normal vector orthogonal to the superior and inferior endplates was used to identify candidate elements that belong to the vertebral endplates. Finally, a Fuzzy C-means classifier [5] was invoked to cluster the previously selected surface elements into superior and inferior endplates. The surface meshes for intervertebral discs and simplified vertebral bodies were constructed using the Delaunay algorithm [6].

RESULTS AND DISCUSSION

In this study our methodology was evaluated on the lumbar region of an individual with congenital scoliosis. However, the proposed methodology could be extended for different types of vertebrae such as sacral, thoracic and cervical ones.

The proposed method allows the reconstruction of a simplified spine geometry without considering the spine process, since only the detected superior and inferior endplates are used to reconstruct the intervertebral discs. However, they can also be used for the reconstruction of a simplified geometry of the entire vertebral body. Frontal and lateral views of the detailed geometry including the segmented vertebral bodies and reconstructed inter-vertebral discs are shown in Figures 2A and 2C, respectively, while Figures 2B and 2D represent the simplified patient-specific spine.

CONCLUSIONS

In conclusion, we have presented a novel approach for the three-dimensional reconstruction of vertebral endplates based on a robust and fully automatic algorithm. Both efficiency and accuracy requirements were considered and addressed in the design of the algorithm, which saves the previously manually performed cumbersome task of manual identification of the endplates by means of placement of landmarks.

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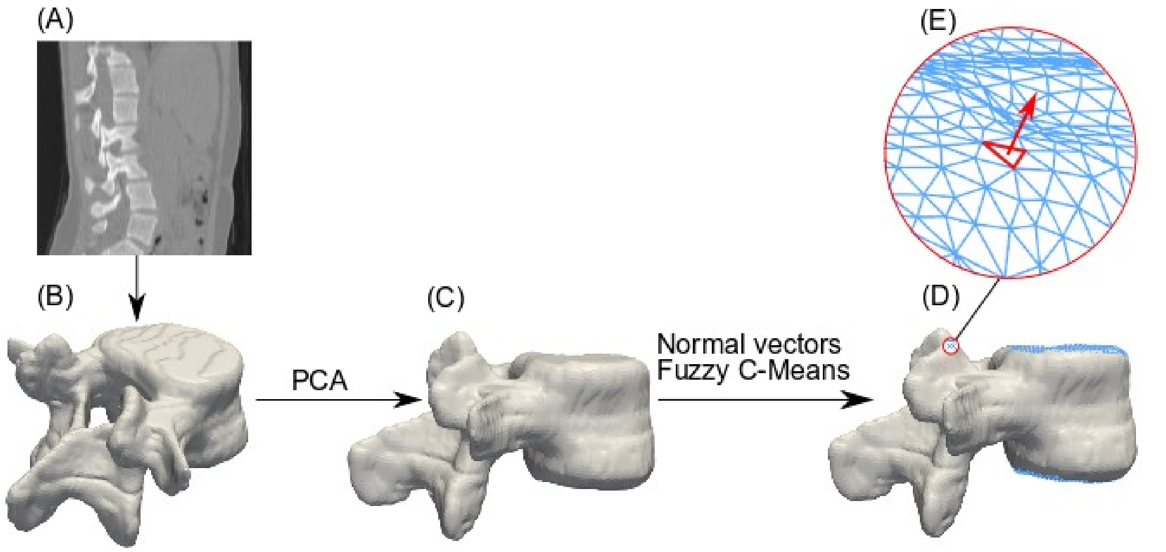

Figure 1: Illustration of the fully automatic algorithm: (A) Patient-specific image data, (B) reconstructed 3D model, (C) shape in the principal component space, (D) detected superior and inferior endplates, (E) illustration of unit normal vector computation for one surface element.

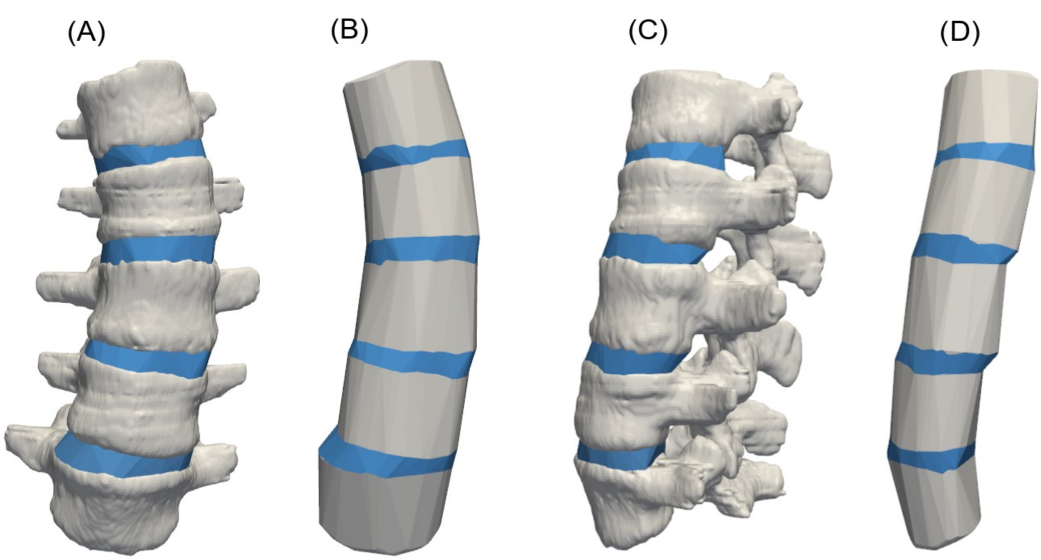

Figure 2: (A) and (C) full frontal and lateral view of the spine geometry including segmented vertebrae and reconstructed intervertebral discs, (B) and (D) frontal and lateral views of the simplifed spinal geometry without vertebra processes.