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Mice endplate segmentation from micro-CT data through graph-based trabecula recognition

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Abstract

Though segmentation of spinal column from medical images have been intensively studied for decade, most of the works were concentrated on the segmentation of the vertebral body and arch, instead of the endplate. Recently, the increasing study on degeneration analysis of vertebra and intervertebral disc (IVD) make endplate segmentation as important as others. While the accurately segmentation of mice endplate from micro computed tomography (CT) images is challenging. The major difficulties include potential high system payload and poor run-time efficiency resulting from high-resolution micro-CT data, highly complicated and variable shape of the vertebra tissues, and the ambiguous segmentation boundary due to the similarity of spongy structures inside both the endplate and its adjacent vertebral body. To solve the problems, the core idea of the proposed method is to identify trabeculae between the endplate and the body through a graph-based strategy. In addition, in order to reduce the data complexity, an endplate-targeted region of interest (ROI) extraction method is introduced according to the analysis of spatial relationship and variety of bone density of vertebra. Furthermore, shape priori of endplate in both two-dimensional and three-dimensional are extracted to assist in the segmentation. Finally, an iterative cutting procedure is implemented to produce the final result. Experiments were carried out which validate the performances of the proposed method in terms of effectiveness and accuracy.

Keywords

Vertebrale endoplate, Segmentation, Harmonic field

1. Introduction

Demanded by image-based spine assessment, biomechanical modeling and surgery simulation, segmentation of spinal column from medical images have been intensively studied for decades. In former researches, most of the works were concentrated on segmenting vertebral tissues such as the body and arch, while vertebral endplate segmentation were rarely mentioned. However, endplate is as important as the others. As a transitional zone between the intervertebral disc (IVD) and vertebra, it not only plays an important role in containing the adjacent disc, distributing applied loads evenly to the underlying vertebra, but also serves as a semi-permeable interface that allows the transfer of water and solutes, preventing the loss of large proteoglycan molecules from the disc [1, 2]. Recently, it is also believed that there has a close relationship between the harm of endplate and osteoporosis [3]. Therefore, endplate segmentation could become an important pre-requisite of vertebra/IVD degeneration analysis and many other applications, which is a major motivation of this work.

Up to now, endplate segmentation from computed tomography (CT) images accurately is still a challenging task in practice, which relies heavily on knowledge, experience, and manual works [4]. The main difficulties can be concluded as follows.

- *Potential high system payload and poor run-time efficiency.* The average thickness of endplate is generally less than 80 μm; therefore, a high-resolution imagery such as the micro-CT technique is required in order to achieve a high-accuracy segmentation. While, high resolution often leads to high system payload and poor run-time efficiency.

- *Highly complicated and variable shape of the vertebra tissues.* The shape of vertebra including the endplate, body and arch are highly complicated and variable. For example, the mice vertebra mice we test have transverse processes relatively longer and of larger curvature comparing to the human's. Therefore, mice vertebral body and arch are more likely to be interrupted with each other; it is more difficult to separate them properly. Besides, existing algorithms designed for human vertebrae may not be suitable for our case anymore.

- *Ambiguous segmentation boundary.* Both the endplate and body are composed of spongy cancellous bone (see blue and green region marked in Fig. 1a), which makes the segmentation boundary ambiguous. Though there exists a gap area (labeled with a yellow dotted line in Fig. 1b) between them, however, the gap is considerably narrow and divided by trabeculae, which means it is difficult to find a proper continuous curve as a segmentation boundary.

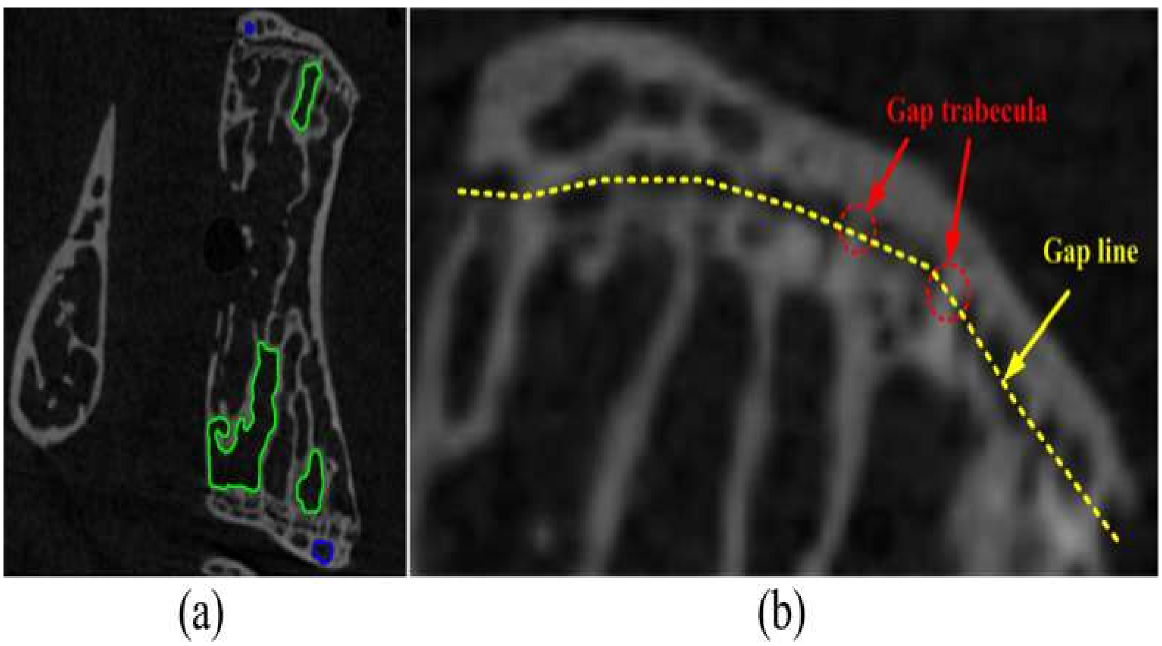

Fig. 1 Demonstration of endplate segmentation difficulties. **a** A sagittal view of the micro-CT data, where the blue and green marked the spongy structure caused by the cancellous bone. **b** Zoom in view of the endplate and its adjacent vertebral body region, where two of the gap trabecular and the gap line are labeled in red and yellow respectively

As we mentioned above, though few works could be found on endplate segmentation, plenty of researches have been done to achieve detection and segmentation of vertebrae [5, 6, 7, 8, 9], spinal canals [10], and spinal cord [11].

For the purpose of separating the neighboring vertebrae roughly, Zhao et al. [12] proposed a neighboring point rating method based on constructing membership grade to form a virtual plane to cut adjacent processes. The method proposed by Kim et al. [9] searches a ray emitted from the stared point among the center axis of the spine and further construct a three-dimensional (3D) surface by propagating the ray to detect the accurate gap area between two processes.

A common strategy to reduce the data complexity is by limiting the algorithm applied to a relatively small region of interest (ROI) [13]. In order to identify the ROI, Athertya et al. [5] extract the Harris corners [14] among the possible vertebra region to detect the vertebra range. However, the detection needs several interactions and training in advance, meanwhile the accuracy of detection depends on the selection of multistage seed points. Cheng et al. [6] detect the vertebra region by a probabilistic map computed from a voxel-wise classifier and use mean shift algorithm to estimate the ROI after annotations.

In our work, we also need to isolate individual vertebra from a given vertebral column, to extract the ROI for data complexity reduction, while more importantly, to segment the endplate, and we made it in a endplate-targeted way. Specifically, taking micro-CT images as input, we aim to develop an intelligent framework to accurately segment the endplate from the others. And the core idea is to recognize the trabeculae (e.g., marked by red circles in Fig. 1b) within the narrow gap formed by the endplate and its adjacent vertebral body by a graph-based algorithm. The proposed framework can be separated into four parts, which are (1) pre-processing, (2) priori shape extraction, (3) gap trabecula detection, and (4) trabecula cutting and refining. Particularly, we firstly isolate each vertebra and identify the ROI for endplate in a top-down basis (Section 2.1). Secondly, shape priori in both 2D and 3D are introduced to offer constraints for later graph cuts based trabeculae recognition (Section 2.2). After that, a graph will be constructed based on mask skeletonization before the graph cuts based trabeculae recognition (Section 2.3). Finally, we find an optimal cutting strategy to remove the redundant connections properly (Section 2.4). An accurate result can be achieved after these processes, which is ready for subsequent operations such as the 3D reconstruction.

2. Materials and Methods

The experimental data we used were collected from the animal laboratory of spinal surgery of the Xiangya Hospital. Micro-CT technique is adopted due to the high-quality imagery requirement. To capture the data, mice of different ages were fixed in a slot scanned by a Bruker SkyScan1172 micro-CT scanner. The in-plane resolution of the image is 7.27 μm × 7.27 μm, and the slice spacing is 7.27 μm. Figure 2 demonstrates a typical data of the inputs, which contains 4 lumbar vertebrae.

Fig. 2 The sagittal, coronal, and axial views of the input data

2.1 Pre-processing

The aim of the pre-processing is to get proper ROI for the endplates. In this work, a top-down strategy which consists of three steps as shown in Fig. 3 is proposed to achieve the goal from coarse to fine.

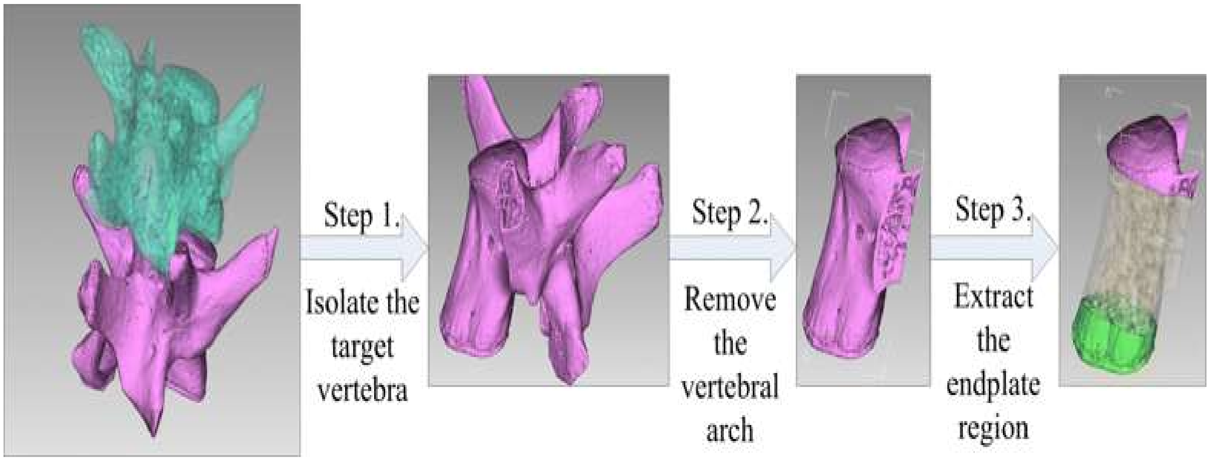

Fig. 3 The workflow of the proposed pre-processing

The first step is to isolate the vertebra from each others. Other than finding separation lines or surfaces such as the method proposed by Kim et al. [9], thanks to the high resolution of micro-CT image and unconnected spatial relationship among different vertebrae, this step can easily be done by 3D region growing on the mask resulting from a Otsu threshold.

The second step finds out ROI for endplate within each axial slices. Due to the shape complexity mentioned above, it is normally impossible to completely cut off the vertebral arch by planes as proposed in existed methods [12, 15]. To remove useless regions as many as possible, an optimal cylinder will be computed automatically in our method to meet the quasi-cylindrical shape of the vertebral body as shown in the right of Fig. 4. The cylinder can be obtained by topology analysis of the vertebra beginning from both the top and bottom part to the center part in axial planes slice by slice as indicated by blue arrows in Fig. 4. Because in this way, we could find two regions indicated by R_1 and R_2 in Fig. 4 which cover the entire endplate. Then, based on the projection of bone regions within R_1 and R_2, we can easily find a circle (e.g., C_1 in Fig. 4) which can be used to define the target cylinder.

3. Results and discussion

In this section, experiments designed to evaluate the performance of the proposed method will be presented. All experiments were carried out on a common personal computer with a Intel Core i3 processor (3.5 GHz) and 8 GB memory.

3.1 Experiment for shape prior extraction

In Section 2.2, we proposed two kinds of shape prior, which are the 3D gap line on the mesh surface and the 2D gap line within CT slices. Since the 3D gap line serves as the foundation of the 2D gap line detection, its extraction performance is firstly assessed.

3.1.1 *Shape prior extraction results*

We test effect of the proposed shape prior extraction method by employing it for all vertebra in our data set. The (1) generated harmonic field, (2) isoline candidates and (3) resulting 3D gap line of a randomly selected vertebra are shown in the first row of Fig. 11 from left to right respectively. Since the 3D gap line will be further transformed into two terminal points of the 2D gap line, Fig. 11 also shows the corresponding terminal points (i.e., the red dots) within some typical slices, whose index are labeled on the top-right of the slice image. From the figures, we can see that both the 3D gap line and terminal points are correctly detected.

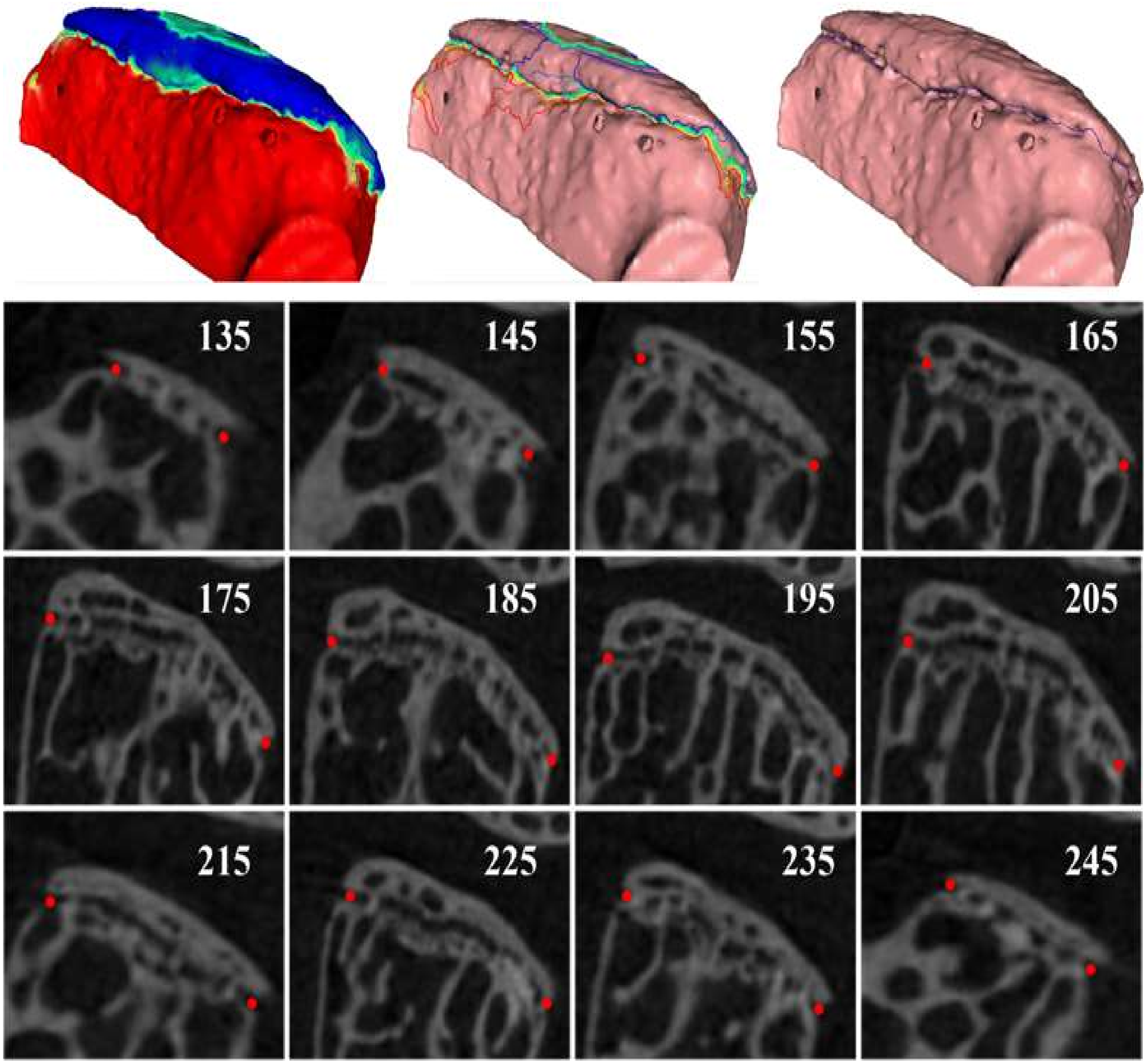

Fig. 11 Experimental results of shape priori extraction. The generated harmonic field, isoline candidates and the resulting 3D gap line of a randomly selected vertebra are shown in the first row from left to right respectively. The rest part shows the terminal points corresponding to the 3D gap line within some typical slices

4. Conclusion

In this paper, an intelligent framework is proposed to segment each endplate from micro-CT data captured from the vertebral column of mice. The innovations of the proposed method can be summarized as the following three aspects. Firstly, this work is one of few researches which focus on endplate segmentation. Secondly, we solve the endplate segmentation as a recognition problem of trabeculae within 2D gap area formed by target endplate and its adjacent vertebral body by a graph-based strategy. Thirdly, both 3D and 2D shape priori of the vertebra are used to guide for the segmentation, which are extracted by a harmonic field-based ranking method and a spline-fitting method respectively.

To assess the proposed method, experiments for shape prior extraction, accuracy and efficiency evaluation, and demonstrations of the segmentation results are presented and discussed in details, which proved the effective and efficiency of this work. However, there still have some works that could be done in the future including improvement of the accuracy and efficiency by incorporating more reliable shape priori and optimizing the graph cut-related procedures, since it consumes half of the total time as shown in the experiment.

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