Automated extraction method for the center line of spinal canal and its application to the spinal curvature quantification in torso X-ray CT images

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ABSTRACT

X-ray CT images have been widely used in clinical routine in recent years. CT images scanned by a modern CT scanner can show the details of various organs and tissues. This means various organs and tissues can be simultaneously interpreted on CT images. However, CT image interpretation requires a lot of time and energy. Therefore, support for interpreting CT images based on image-processing techniques is expected. The interpretation of the spinal curvature is important for clinicians because spinal curvature is associated with various spinal disorders. We propose a quantification scheme of the spinal curvature based on the center line of spinal canal on CT images. The proposed scheme consists of four steps: (1) Automated extraction of the skeletal region based on CT number thresholding. (2) Automated extraction of the center line of spinal canal. (3) Generation of the median plane image of spine, which is reformatted based on the spinal canal. (4) Quantification of the spinal curvature. The proposed scheme was applied to 10 cases, and compared with the Cobb angle that is commonly used by clinicians. We found that a high-correlation (for the 95% confidence interval, lumbar lordosis: 0.81-0.99) between values obtained by the proposed (vector) method and Cobb angle. Also, the proposed method can provide the reproducible result (inter- and intra-observer variability: within 2°). These experimental results suggested a possibility that the proposed method was efficient for quantifying the spinal curvature on CT images.

Keywords: X-ray CT images, Spinal curvature, Spinal canal, Cobb method, Median plane image of spine

INTRODUCTION

Healthcare of spinal disorders, including low back pain and vertebral fracture, is an extremely important social issue. In recent years, X-ray computed tomography (CT) images have been widely used in clinical practice. In CT images, we can observe not only the target organs and tissues but also the spine. It may also be useful to detect spinal disorders during an X-ray CT assessment.

Alterations in the spinal sagittal curvature are related to the progression of spinal disorders such as spondylosis, intervertebral disc degeneration, osteopenia, and osteoporosis [1-5]. The aim of this study was to design a computer-

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assisted scheme for the evaluation of spinal sagittal curvature on X-ray CT images. Parts of this research have been described in our previous studies [6, 7].

METHODS

The outline of our proposed scheme is shown in Fig.1. The proposed scheme includes four parts. Details of each step are described below.

1.1 Skeletal region extraction

The CT numbers of skeletal regions are higher than those of the other organs and tissues in CT images. Therefore, the thresholding or region growing based CT number is used for extracting the skeletal regions [8] (Fig.1 (c)).

1.2 Center line of the spinal canal (SC) extraction

After the extraction of skeletal regions, skeletal regions are divided and classified into the different parts using implicit anatomical knowledge (Fig.1 (d)). SC region is extracted by propagating the holes inside vertebrae by this scheme [8]. And then, center line of SC is determined by detecting the position of the SC centroid in each slice (Fig.1 (e)).

1.3 Median plane image of spine (MPIS) generation

MPIS generation can be considered as detections of spine location and orientation. We consider the center axis of the SC to the spine axis. MPIS is a curved surface that passes through the spine axis. We deform the spine axis to ensure that all the voxels in the spine axis are located in the same sagittal section (median plane) on CT images. The deformation is only performed in lateral direction to avoid further distortion of the spine (Fig.1 (f)). In this example, we can see that the whole SC can be observed on MPIS (Fig.1 (f)), while the SC around L1 cannot be observed on one sagittal CT section (Fig.1 (b)).

1.4 Quantification of the spinal sagittal curvature

The centerline of the SC is assumed to be a set of vectors, and the spinal sagittal curvature is defined as the angle between two vectors. We term it the "vector method." One vector is determined by the position of the upper end plate and the lower end plate in the vertebral body. These positions are determined by observer interactions; therefore, selection of four key slices (t_u, t_l, b_u, and b_l) as shown in Fig.1(g) is required for the observer to quantify the spinal sagittal curvature. The vector angle, VEC, is defined by the following equations:

$$\mathrm{VEC} = \cos^{-1}\left(\frac{\vec{\mathbf{T}}\cdot\vec{\mathbf{B}}}{|\vec{\mathbf{T}}||\vec{\mathbf{B}}|}\right)\cdot\frac{180}{\pi}[\mathrm{degrees}], \tag{1}$$

$$\vec{\mathbf{T}} = \left(\mathbf{v}[t_l]_y - \mathbf{v}[t_u]_y, t_l - t_u\right), \tag{2}$$

and

$$\vec{\mathbf{B}} = \left(\mathbf{v}[b_l]_y - \mathbf{v}[b_u]_y, b_l - b_u\right), \tag{3}$$

where π denotes a circular constant and $\mathbf{v}[i]$ denotes the coordinate of the SC centroid on the i-th slice. An example of quantification by the vector method, which defined L1 and L5 as the end vertebrae, is shown in Fig.1 (g).

RESULTS

The proposed scheme was applied to 10 CT cases. Each CT case covers the whole torso region with an isotropic spatial resolution of 0.6-0.8 mm and a 12 bits density resolution. The proposed scheme was evaluated at L1-L5 by 3 observers (radiological technologist, anatomical expert, and technical expert). The radiological technologist measured three times. The span of each measurement was one week or more. Each observer measured the Cobb angle [9] and the VEC angle on the sagittal MPIS. We found that a high correlation (for the 95% confidence interval, lumbar lordosis: 0.81-0.99) between VEC and Cobb angles measured by a radiological technologist (see Fig.2). Also, we confirmed the proposed scheme can provide the reproducible result (inter- and intra-observer variability: within 2° as shown in Table 1).

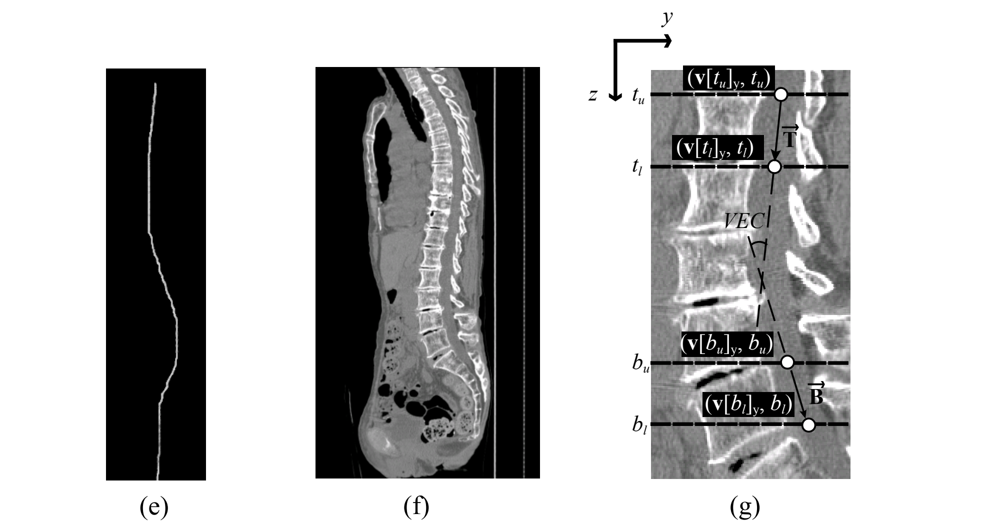

Fig.1 Flowchart of the proposed scheme. (a) CT images (coronal one section), (b) CT images (sagittal one section), (c) Skeleton extraction (3-D view), (d) Skeleton classification (each color shows classified skeletal parts, 3-D view), (e) Center line of the spinal canal (SC) extraction (3-D view), (f) Sagittal median plane image of spine (MPIS), (g) Sagittal curvature quantification on sagittal MPIS .

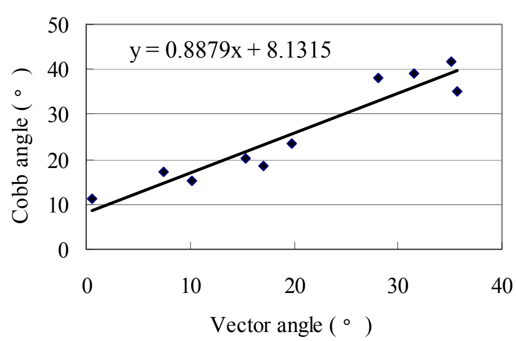

Fig.2 Scatter diagram of the spinal sagittal curvature quantification between the vector and Cobb methods by a radiological technologist.

Table 1 Measurement values of the spinal sagittal curvature at L1-L5 (mean ± standard deviation).

Method	Intra-observer	Inter-observer
Cobb (°)	25.97±1.96	26.44±1.41
VEC (°)	20.09±0.82	19.79±0.89

4. CONCLUSION

We developed a scheme which could quantify the spinal sagittal curvature on CT images. Experimental results showed that the proposed (vector) method had the high correlation with Cobb angle and high reproducibility. Therefore, the possibility that the proposed scheme was efficient for quantifying the spinal sagittal curvature was suggested. Future plans are to demonstrate the robustness of the proposed scheme, to demonstrate the reliability of the proposed scheme on the basis of the statistical analysis, and to design the approach which supports to interpret the spinal curvature in three-dimensions.

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