Computer aided diagnosis for osteoporosis based on spinal column structure analysis

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ABSTRACT

Patients of osteoporosis are comprised of about 11 million people in Japan and it is one of the problems that have gained society. For preventing the osteoporosis, obtaining early detection and treatment are necessary. Multi-slice CT technology has been improving for three dimensional (3D) image analysis, higher body axis resolution and shorter scan time. 3D image analysis using multi-slice CT images of thoracic vertebra can be used for supporting diagnosis of osteoporosis. Simultaneously, this analysis can be used for lung cancer diagnosis which may lead to early detection. We develop automatic extraction and partitioning algorithm for spinal column by analyzing vertebral body structure, and the analysis algorithm of the vertebral body using shape analysis and a bone density measurement for the diagnosis of osteoporosis. An effective result was provided for the case including an insufficient complicated vertebral body bone fracture by the conventional method.

Keywords: osteoporosis, multi-slice CT images, spinal column, vertebral body

1. INTRODUCTION

Currently, about 11 million people have osteoporosis in Japan. The third cause for bedridden patients is the fracture due to osteoporosis. Majority of patients with osteoporosis are women of more than 60 years old. Osteoporosis is one of the problems the aging society has. It is known that the bone mass of the vertebral body that composes the spine decreases when it gets osteoporosis. Therefore, it is necessary to check the bone mass regularly to prevent osteoporosis. Recently, multi-slice CT development made it possible to obtain high resolution images. Specifically, the rapid improvement of resolution in the direction of the body axis, thus the 3D image analyses using computer became possible. Because information on the dorsal and the lumbar vertebra is included in the image of the chest and the body obtained by multi-slice CT, it is possible to capture the change in the bone mass by 3D analysis of the chest and the lumbar vertebra. In addition, it allows detailed analysis and evaluation of vertebral body that will lead to early detection of the osteoporosis.

This study is for building a system effective in case including an insufficient complicated bone fracture vertebral body by a conventional method[1]. We develop an automatic extraction and partitioning algorithm of spinal column which is effective in analyzing a complicated bone fracture vertebral body, and the analysis algorithm of the vertebral body using shape analysis and a bone density measurement for diagnosis of osteoporosis.
2. MULTI-SLICE CT IMAGES AND STRUCTURE OF VERTEBRAL BODY

This algorithm employed multi-slice CT images taken by normal-dose in general clinical field. We used Aquilion Toshiba in the present study. The conditions for a detailed investigation of normal-dose and high resolution multi-slice CT images are as follows: beam width: 1 mm; reconstruction intervals: 1 mm; tube voltage: 120 kV and tube current: 100-500 [mA]. The average number of slices per scan in our data is 300 slices. Each slice is 512x512 pixels, and pixel size is 0.551 - 0.680 mm. Figure 1 shows an example obtained by multi-slice CT images. The proposed algorithm is necessary for a 3D analysis.

The vertebral body is divided into two parts, the cortical bone, a hard and exact structure with which the vicinity of the surface is covered, and the cancellous bone, with a spongy structure found inside. Intervertebral is between the vertebral bodies, serves as a cushion and is called a cortical bone endplate and particularly a vertebral body and intervertebral boundary. The vertebra is composed of the cervical vertebra, the dorsal vertebra, and the lumbar vertebra, composed of 7 pieces, 12 pieces, and 5 pieces respectively. Figure 2 shows the structure of the vertebral body and the structure of the vertebral.

<table>
<thead>
<tr>
<th>Normal dose</th>
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<tr>
<td>Tube voltage [kV]</td>
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<tr>
<td>Tube current [mA]</td>
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<tr>
<td>Beam width [mm]</td>
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<td>Images size [pixels]</td>
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<td>1.0</td>
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<td>1.0</td>
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<tr>
<td>0.551 - 0.680</td>
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<td>512x512</td>
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Figure 1. Multi-slice CT image. (WL: 1500 WL: -500).

Figure 2. Structure of vertebral and vertebral body
3. METHOD

This algorithm extracts the vertebral body by inputting the 3D Torso multi-slice CT images. Shape and the bone density value of the extracted vertebral body are analyzed. Osteoporosis is evaluated from these analytical results.

The osteoporosis diagnosis support algorithm is executed in four steps. Step 1: extracting a spinal column using distance transformation. Step 2: structure analysis of spinal column. The structure is classified from the extracted spine, and encoded by using the result of the classification like the state transition according to the center line of the spine. Step 3: partition of spinal column. Integrate both of the result that was extracted using the pattern of the state transition cord, and the result that extracted using an intervertebral foramen and decide the partition of the spinal column. Furthermore, we decide the position of the first thoracic vertebra using a costal position and give a vertebral body number on the basis of this. The vertebral body is analyzed in step 4, Bone fracture detection using pattern of the state transition cord defined in Step2, and the shape measurement of the vertebral body. A bone density uses the correlative value derived from the computation of phantom, and compared it with the average YAM (Young Adult Mean) from 20's to 40's, and the judgment result of osteoporosis is outputted at the end. Figure 3 shows the processing procedure of the osteoporosis diagnosis support algorithm.

As for the evaluation of osteoporosis, the vulnerability fracture is evaluated from the result of the shape analysis of the vertebral body. Osteoporosis is decided immediately if fracture is found regardless of the degree of vulnerability. If the fracture showed no vulnerability, bone density is analyzed. If less than 70% of young adult mean value (YAM), it is judged as osteoporosis, if 70 - 80% judged as bone mass decrease, and if 80% or more, it is judged as normal. Figure 4 shows the clinical pathology of osteoporosis.

![Algorithm as a support for the diagnosis of Osteoporosis.](http://proceedings.spiedigitallibrary.org/ss/ TermsOfUse.aspx)
3.1 Extraction of bone region

A threshold is processed to the input image (100.H.U.), and the bone region is extracted based on connection. In addition, the threshold in the vicinity of the sternum is set to (80.H.U), and the costal cartilage is extracted. The processing in the bone region is done by the closing operation and next the bone region (including vertebra, ribs, clavicle, sternum, and shoulder blade) is extracted. Figure 5 shows the extraction result.

![Figure 5. Result of bone region extraction and closing.](image)

3.1 Extraction of spinal column

A distance transformation is processed to the extracted bone region. The area where it touches the back is extracted from the calculated distance value with the thickness of about 10 mm or more as a spine bone candidate area. The extracted area is expanded by using a reverse-distance transform, and it is assumed as the area of the spine. Figure 6 shows the extraction result. The vertebral body is extracted to limit the area used for the bone density evaluation, and the vertebral body and the vertebral arch are separated.

The triangle is made from the center of gravity point of the body for the front side of the body. A part of costal cartilage of the sternum and the collarbone included in the area is classified. In addition, the rib is extracted from the part where it touches the rectangular domain of the spine. The center of gravity point in the part where the rib touches the rectangular domain is assumed to be a center of gravity point of the rib. Figure 7 shows the classification result of the bone region.
3.2 Spinal column partition

A four-dimensional curvature is obtained to the extracted spine bone area. The direction vector of the maximum main curvature extracts a vertical pixel to a center axis of the spine as an end plate area candidate. The end plate area is decided by using the location information of the center of gravity point of the rib previously searched. The extracted end plate is made to be a boundary and the sponge bone area is classified. Using a classified result, we encoded the structure along the center line of the spinal column as in condition transition. The vertebral body is divided by encoding the transition of the state along the centerline of the vertebral body by using the result of the classification, and detecting an intervertebral pattern. Fig. 8 shows the extraction example, and Figure 9 shows the example of detecting an abnormal part.
3.3 Shape analysis of vertebral body

Leading edge volume (A), central volume (C), and trailing edge volume (P) of the vertebral body are shown in Figure 8. The decreases for A/P are less than 0.8, C/A or C/P is less than 0.75 and the A/P from A of the wedge vertebra, the high rank or the subordinate position, C, and P by 20% or more is defined as the vertebra plane, and these are judged as the vulnerability fractures. The vulnerability fracture is chiefly seen from the fourth dorsal vertebra on the fourth lumbar vertebra in osteoporosis case. The vulnerability fracture is defined as a decrease in the height of the vertebral body. Then, the height of the vertebral body is measured along a center axis of the spine. The vertebral body is divided into nine areas, and A, C, and P are decided from the height of the average of each area. As a result, the vulnerability fracture that was not discovered at the early stage of vertebral body is confirmed by this classification. The processing results are shown in Figure 10.

3.4 Bone density analysis of vertebral body

If less than 70% of young adult mean value (YAM), it is judged as osteoporosis, if 70-80% judged as bone mass decrease, and if 80% or more, it is judged as normal. As for the bone density analysis, the bone density of the sponge bone area where the remarkable bone mass decrease is evaluated. Average CT value of the sponge bone area is calculated, and the bone density value is determined based on the conversion chart of Figure 11. This conversion chart is an examination of the correlation of the bone density and the CT values by using the bone mass phantom. It has been used for evaluating the YAM value for 20 years old through 44-year-old bone density (conversion with the correlation table).
4. EXPERIMENTAL RESULTS

We applied the algorithm to 40 bone fracture cases obtained from 567 chest data collected from 2006 through 2009. Results show that extraction of the vertebra was 97.5% possible (39 cases out of 40 cases), in the thoracic vertebra 100% possible (40 cases out of 40 cases). One case that failed was due to indistinct cervical spine. The bone density of the vertebral body of 40 cases where the fracture is not admitted was analyzed, and the normal, with a bone mass decrease and with osteoporosis candidates were evaluated. The bone density used and calculated YAM value calculated from the bone mass phantom. We show shape analysis result in Fig 12. A comparison result with YAM in Fig 13.

Figure 11. Standard curve

![Standard Curve](image1)

![Tools employed](image2)

Figure 12. Example of shape analysis. a) non-fracture, b) c) fracture.

![Shape Analysis Result](image3)

Figure 13. Comparison result with YAM

a) Young Adult Mean (YAM)
b) Comparison result with YAM
5. CONCLUSIONS

We developed the automatic extraction algorithm of the vertebra, and the analysis algorithm of the vertebral body using shape analysis and a bone density measurement for the diagnosis of osteoporosis. We showed that the vulnerability fracture could be detected by evaluating the shape of the vertebral body from the result of the experiment. In addition, it was shown that we could confirm the symptom of osteoporosis by evaluating the bone density. Therefore, the algorithm that we developed may be a potential and useful tool for the diagnosis of osteoporosis.

REFERENCES
